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Aviation and ground systems must increase use of emerging and advanced technologies to remain viable in complex, future battlefield environments. Unmanned vehicles will become part of future military operations due to: the demand for immediate intelligence on the battlefield, decreasing defense budgets, increasing operational tempos, and the low tolerance for casualties by the public. This work develops and evaluates system level concepts that fulfill these overall requirements using an unmanned hybrid vehicle. The unmanned hybrid vehicle combines the attributes of an autonomous vertical takeoff and landing air vehicle and an autonomous ground vehicle. This allows fast, flexible deployment and quiet, longer duration ground missions. The assumed time of deployment is the year 2012. The study included requirements definition, concept synthesis, and down selection to three final configurations. Engineering students from the University of Alabama in Huntsville and Ecole Supérieure des Techniques Aéronautiques et de Construction Automobile participated on three competing design teams. Team 1 developed a basic system with coaxial rotors and a fuel cell drive system. The system is one unit that can both fly and operate on the ground. Team 2 developed a separate air and ground vehicle with intermeshing rotors. The integrated ground unit is deployed and retrieved by the air system. Team 3 also developed a separate air and ground vehicle but with a single rotor system that also requires a tail rotor.

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Unnamed Hybrid Vehicle

Final Report – Volume III
IPT 2

Submitted By:

UAH Integrated Product Team 2002

IPT 2002

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Unmanned Hybrid Vehicle

IPT 2

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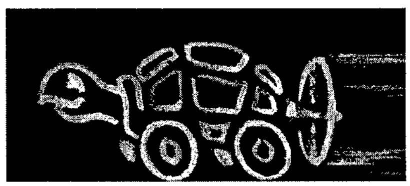
HYBRIDS R US



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The University of Alabama in Huntsville	The American Helicopter Society
Snecma	Quality Research
Sigma Services of America	HDC
SAIC	Sandia National Laboratory

The University of Alabama in Huntsville
April 25, 2002

Executive Summary

English

In today's world technology is increasingly becoming more and more advanced. This is indeed true for the current day battlefield. The military is relying heavily on unmanned vehicles to detect battlefield obscurants and chemical and biological threats, as well as to perform surveillance operations. With a Unmanned Hybrid Vehicle (UHV), troops are not endangered, and due to the smaller size of the vehicle it will not be easily observed. Hybrids R Us has developed a UHV, The Mole, to meet the demands set forth by the customer in the Concept Description Document (CDD). Using a two-piece system, The Mole can fly in at Nap-Of-The-Earth (NOE), ahead of the military troops, drop off the ground vehicle and complete the required mission. All technologies used to design this UHV are available today, which will allow The Mole to be deployable by the year 2012.

French

En monde d'aujourd'hui la technologie devient de plus en plus de plus en plus plus avancée. Cela vaut en effet pour le champ de bataille courant de jour. Les militaires comptent fortement sur les véhicules non-pilotés pour détecter les menaces d'obscurants de champ de bataille, chimiques et biologiques, aussi bien que pour effectuer des opérations de surveillance. Avec un UHV, des troupes ne sont pas mises en danger, et en raison de la taille plus petite du véhicule on ne l'observera pas facilement que. Les hybrides R nous a développé un véhicule hybride non-piloté (UHV), la taupe, pour satisfaire les demandes déterminées par le client dans le document de description de concept (CDD). En utilisant un système en deux pièces, la taupe peut voler dedans à la petit-de-terre (NOE), en avant des troupes militaires, se laisser tomber outre du système au sol et accomplir la mission exigée. Toutes les technologies concevaient cet UHV sont aujourd'hui disponible, qui permettra à la taupe d'être deployable par l'année 2012.

UHV Compliance List

The following list details the location of all specification compliances for the UHV. The list shows the location in the CDD, located in Appendix A, provided by the Army of every specification and the location where that specification is dealt with in this proposal

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Common Terms and Acronyms List

Word	Comments
ACTD's	Advanced Concept Technology Demonstrations
AGL	Above Ground Level
AIAA	American Institute of Aeronautics and Astronautics
AMCOM	United States Army Aviation and Missile Command
APU	Auxiliary Power Unit
BLOS	Beyond Line of Sight
BSFC	Brake Specific Fuel Consumption
CAD	Computer aided design
CDD	Document that details the customer's technical specifications for the UHV
CM	Communication
CST	Central Standard Time
DS	Direct Support
EE	Electrical Engineering
EH	English
EM	Engineering Management
EPA	Environmental Protection Agency
EST	Editorial Support Team
ESTACA	Ecole Superieure des Techniques Aeronautiques et de Construction
FLOT	Forward Line of Troops
Ft	feet
FY	Fiscal Year
GCS	Ground Control Station
GS	General Support
HMMWV	High Mobility Multipurpose Wheeled Vehicle
IOC	Initial Operational Capability
IPT	Integrated Product Team
IRP	Intermediate Power Rating
km	Kilometer
lbs	pounds
LRIP	Low-rate Initial Production
MAE	Mechanical and Aerospace Engineering
MDA	Milestone Decision Authority
MI	Military Intelligence
MKT	Marketing
MS	Milestone
MSFC	Marshall Space Flight Center
NBC	Nuclear, Biological, or Chemical
nm	Nautical miles (~2025 yds)
O&S	Operating and Support
Payload	Item carried by the system having a specified weight
PEFC	Polymer Electrolyte Fuel Cell
PM	Program Manager

R&D	Research and Development
RDT&E	Research, Development, Test, and Evaluation
RVT's	Remote Video Terminals
TBD	To be determined (not know at this time)
TBE	Teledyne Brown Engineering
TBO	Time Between Operation
TF/TA	Terrain following/terrain avoidance
TUAV	Tactical Unmanned Aerial Vehicle
UAH	The University of Alabama in Huntsville
UAV	Unmanned Air Vehicle
UHV	Unmanned Hybrid Vehicle
US	United States
VROC	Vertical rate of climb
VTOL	Vertical takeoff and landing
WBS	Work Breakdown Structure

Team-Specific Terms and Acronyms List

Word or symbol	Comments
σ	Solidity
ρ	Air Density at 4000 ft – 2.111E-3
ρ_b	Density of Blades
a	Lift Slope Factor
A_b	Blade Area
AMP	Ampere
A_o	Blade Overlap Area
A_R	Rotor Area
AR	Aspect Ratio
A_t	Total Blade Area Accounting for Overlap Area
b	Number of Blades
c	Blade Chord Length
CCD	Charge Coupled Device
C_D	Coefficient of Drag
CDL	Common Data Link
C_{do}	Parasitic Drag Coefficient
cm	Centimeter
Cmax	Maximum Torque
C_T	Coefficient of Thrust
D	Vehicle Drag
d	Diameter
F	Force
FC	Fuel Consumption
FLIR	Forward Looking Infra-red
f_r	Rotor Frequency
g	Gravity
h	Hour
hp	Horsepower
i	Inflow Factor
in	Inches
k	Power Factor for Hover
km	Kilometer
kW	Kilowatt
L_b	Blade Loading
lbf	Pound Force
L_d	Blade Disk Loading
m	Meter
MIAG	Modular Integrated Avionics Group
N	Newton
p	Blade Pitch in Radians
P	Power
P_i	Induced Power
P_o	Profile Power
P_t	Total Power

R	Blade Radius
RC	Rate of Climb
rpm	Revolutions per minute
RVM	Reconfigurable Vision Machine
s	Stagger - Distance Blades Overlap Each Other
s	Second
S	Circumference
t	Blade Thickness
V	Vehicle Air Speed
v	Velocity
V_b	Blade Volume
V_i	Induced Velocity
V_t	Rotor Tip Velocity
W	Vehicle Weight
W_b	Weight of Blades

IPT 2: Feasibility of Unmanned Hybrid Vehicle

UHV – Unmanned Air/ Ground Vehicle

1.1 The Need

The Unmanned Hybrid Vehicle (UHV) sought by the U.S. Army Aviation and Missile Command (AMCOM) is envisioned to provide essential scouting and target recognition to the military. The UHV will enable the military to perform advanced unmanned operations such as chemical and biological detection, surveillance, and battlefield obscurant detection. This system will enable the military to perform unlike any other military in history. The army will have the advanced capabilities needed to achieve its goals safely and effectively.

The UHV will provide the military with a system that is capable of target recognition and definition. The system can be used in adverse weather, on unimproved roads as defined in the CDD, from any unimproved land facility surface day or night. By using a UHV instead of a manned aircraft, the system will weigh less than 1500 lbs and will be transportable via a HMMWV trailer or UH-60 sling. Numerous missions can be performed by the UHV without the risk of human life.

An Unmanned Hybrid Vehicle is much more versatile and functional than the Unmanned Ground Vehicles (UGV) and Unmanned Air Vehicles (UAV) that are currently in use today. The UHV will be capable of both air and ground missions. The ground vehicle will be deployed further out than the UGV, increasing the secretiveness of the mission and increasing the range as well. A UHV would be able to land and take off on the ground if the enemy were spotted, and then would be able to fly away when necessary, whereas a UAV can only perform air missions and a UGV can only perform ground missions.

1.2 The Requirements

There were many important specifications set forth by the customer, AMCOM. The most important requirements included an air speed of 30 km/h, a VROC of 200 fpm, a ground speed of 6 km/h, a flight profile of hover at full flight, an operational altitude of 0-250 ft AGL, an endurance of four hours, a payload of 60 lbs, an air range of 15 km, a ground radius of 0.5 km, semi-autonomous capabilities, transportable via HMMWV Trailer or UH-60 sling, and a weight of less than 1500 lbs. Throughout the design process Hybrids R US has fulfilled these requirements.

The main challenge for this project was designing a very complex system in the time frame proposed. Many areas of helicopter and ground vehicle design had to be thoroughly examined and researched. Another challenge was using the technology today to produce a product that will be deployed in 2012. Advancements in technology occur on a daily basis; thus designing a system that will meet warfare needs ten years from now presented a difficult and complicated task. In addition, bringing together a diverse group of people to work toward developing a quality product that meets the customer's specifications required an enormous amount of dedication and commitment. Other major challenges included weight and size limitations on the design.

1.3 Solution

The Mole is a UHV that possesses the capabilities of meeting the needs set forth by the customer, AMCOM. Hybrids R Us has worked extremely hard in order to successfully design The Mole. The following sections expand on how The Mole meets the given requirements.

1.3.1 Concept Overview

The Mole, as seen in Figure 1, was conceptually designed by Hybrids R Us to meet the specifications as presented in the CDD. Figure 1 is an artist rendition of The Mole and is therefore not drawn to scale. Table 1 lists dimensional properties of The Mole showing that it will fit in a HMMWV trailer and is also transportable via UH-60 sling. Figure 2 shows three views of The Mole.

The entire system consists of The Mole, as well as a ground station. The Mole is a two-piece concept. The air portion of the vehicle is powered by a Zoche 150 hp engine and utilizes synchropter rotors. The Mole's most efficient cruise velocity is 72 km/h while the ground portion has a velocity of 6 km/h. The ground portion is powered by two electric motors that utilize three 12-volt batteries. The Mole makes use of current technology and will be ready for deployment in 2012.

The Mole utilizes state of the art technology. It is capable of chemical and biological threat detection and will send information to the back to the ground station via secure links. The Mole is the future of unmanned vehicles.

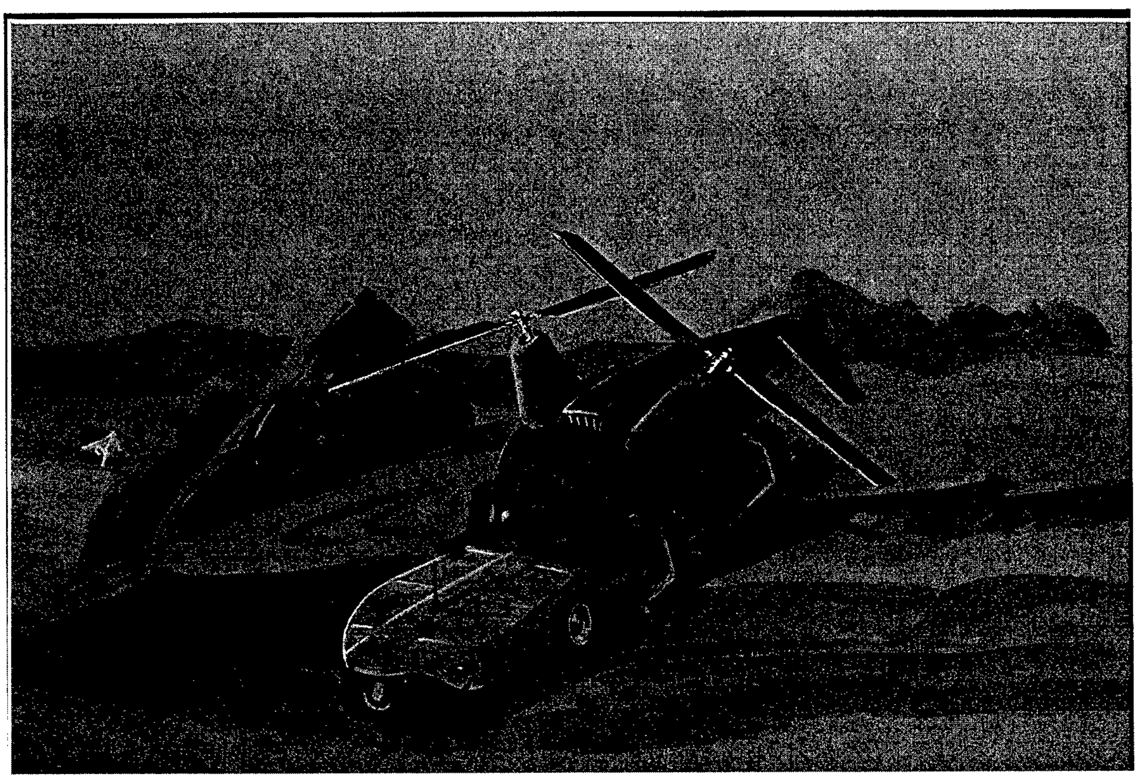


Figure 1 Artist Drawing

1.3.2 Dimensional Properties

Table 1 Dimensional Properties

Overall Dimensions

Ground Unit	4.5' x 2.6' x 2.6'
Air Unit	7.57' x 4.94' x 3.82'

Ground Components

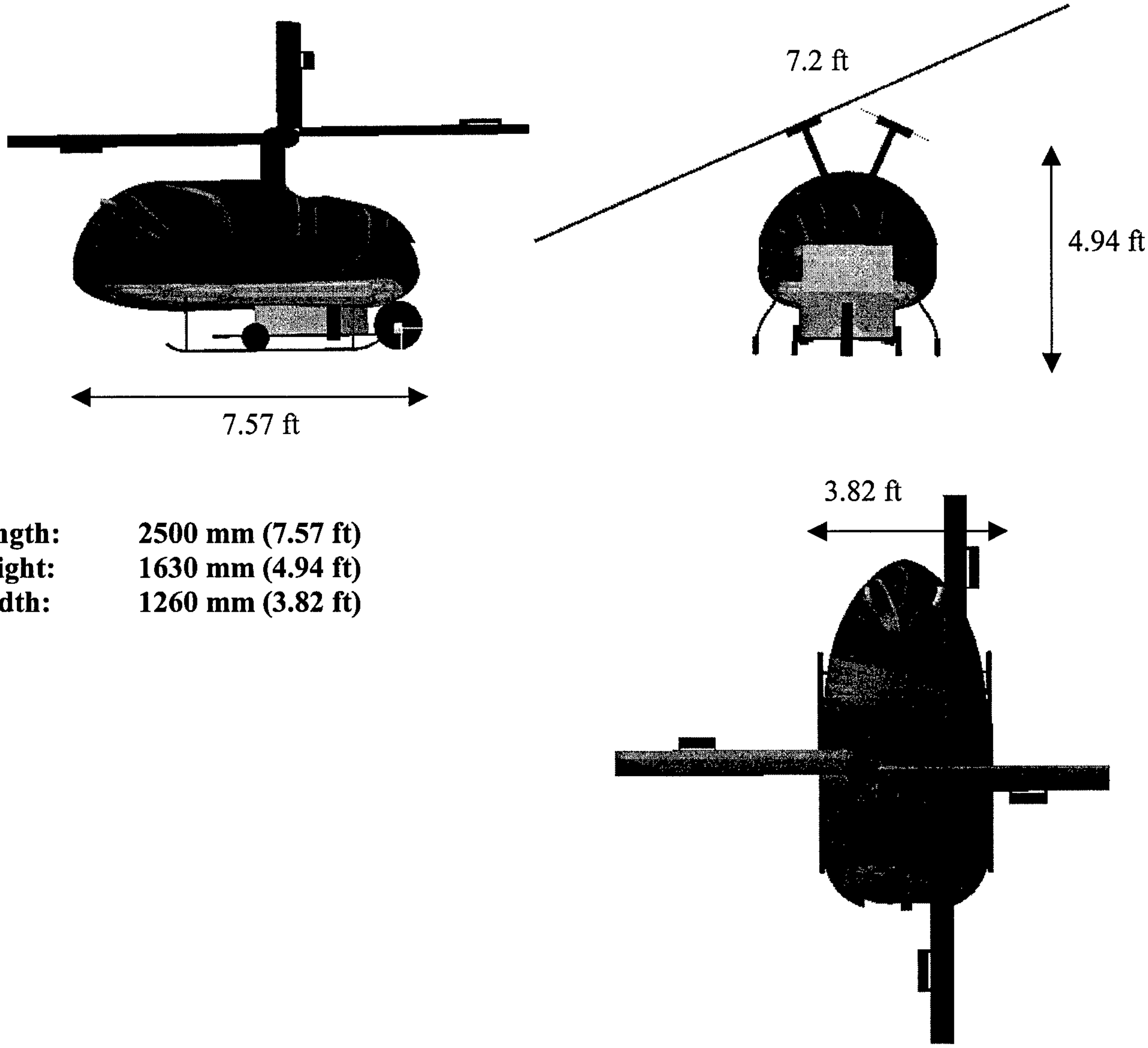
Electric Motors	8" D x 8.4" L
Front Wheels	10" D
Back Wheels	8" D
Batteries	10" x 6.8" x 7.8"

Air Components

Rotors	7.2'
Servo Flaps	3/4ths the distance of the Rotors
Engine	Height - 21.8" Width - 21.8" Diameter- 25.5" Length - 28.5"
Fuel Tank	4700 in^3

Sensors/Avionics

GPS antenna	4.5" D x 3.6" H (circular)
IFF antenna	1" W x 2" L x 3" H (approximate – outside skin only)
VHF/UHF antenna	1.3"W x 6" L x 7" H
SATCOM antenna	14.2" W x 14.2" H x 2.5" D
Internal radios	6" x 6" x 8"
FLIR camera	9" sphere; 13.3" H including swivel mount
Chem/bio sensor	10"H x 10"W x 10" L
Radar altimeter + antenna patch	5.9" x 3.14" x 2.12" 2.9" x 2" x 0.13"
MIAG (IFF, GPS, IGS, sensor/control input)	5" x 5.5" x 6"
Auxiliary computers	Adaptable



Length:	**2500 mm (7.57 ft)**
Height:	**1630 mm (4.94 ft)**
Width:	**1260 mm (3.82 ft)**

Figure 2 Three-View Drawing

The CG is located under the blades.

1.3.3 Operations Scenario

The Baseline Mission Profile, as seen in Figure 3, is divided into twelve segments. Segment one is the engine startup, segment two is the takeoff of the UHV, segment three is the climb to the combat operational altitude with a required VROC of 200 fpm, segment four is the outbound cruise at nap of the earth flight conditions with a required cruise velocity of 30 km/h, segment five is the descent of the UHV, segment six is hover and land, segment seven is the ground mission with a minimum radius of 0.5 km and a minimum velocity of 0.5 km/h, segment eight is the repetition of segments two through seven as required, segment nine is the climb to combat operational altitude at a required VROC of 200 fpm, segment ten is the cruise inbound at nap of the earth with a required velocity of 30 km/h, segment eleven is the descent and segment twelve is hover and land with a 10% fuel reserve. Segments one through six are expected to last approximately one hour, segments seven through eight are expected to last approximately two hours, and segments nine through twelve are expected to last approximately one hour. This gives an overall required endurance of four hours.

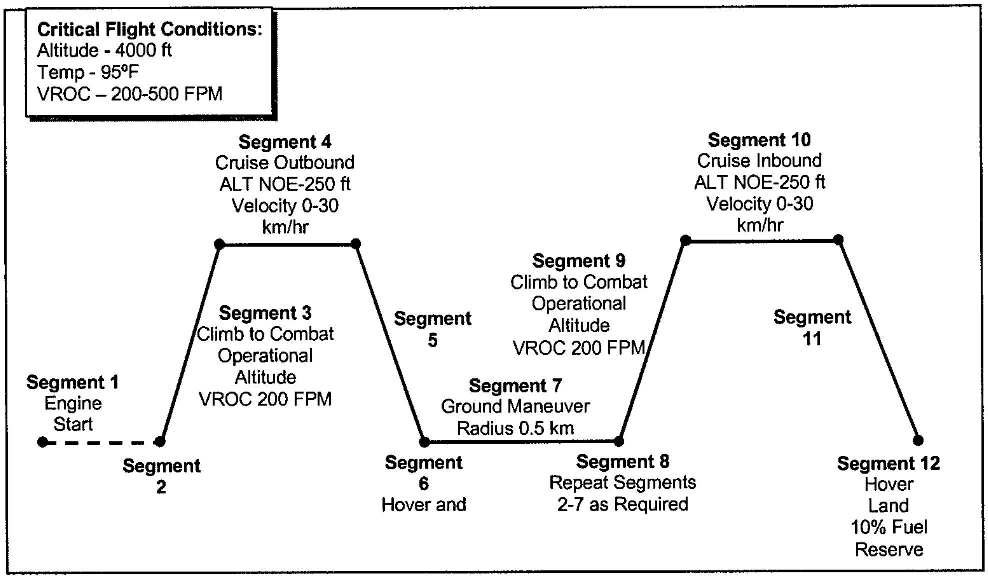


Figure 3 Operations Scenario

Another scenario that The Mole is capable of, is taking off as before, dropping off the ground vehicle, returning to base and retrieving another ground vehicle and dropping it off before picking up the first one and returning home. This would allow multiple ground vehicles to be in use at once, which could easily throw off the enemy if one were a decoy, or multiple missions could be occurring at one time.

1.4 The Performance

Table 2 lists several of the requirements set forth by the customer and the assessment of The Mole relative to those requirements. All requirements were met and some exceeded. With a cruise speed of 72 km/hr, the UHV will be capable of traveling farther in a shorter amount of time. The mission can be completed in a more efficient manner. Information can be gathered and relayed to the troops in a much more timely manner.

Table 2 Final Concept Evaluations - Baseline Mission

CDD Requirement	Requirement	Assessment	Remark
Payload	60 lbs	60 lbs	
Endurance	4 h	4.83 h	**Point to Point**
Flight Profile	Hover-Full	Hover-Full	
Vertical Climb	200 fpm	500 fpm	
Operational Altitude	0 – 250 ft AGL	0-250 ft AGL	
Airspeed	30 km/h	72 km/h	
Ground Speed	6 km/h	6 km/h	
Operation	Semi-autonomous	Semi-autonomous	
Communication	BLOS	CDL	
Transportable	HMMWV, UH-60	HMMWV, UH-60	
Max System Weight	1500 lbs	1487 lbs	
Deployment	2012	2012	

1.5 The Implementation

Table 3 describes the implementation process for the UHV in order for it to be in the field in 2012. This table assumes that the contract for the project will begin in December 2002. The development of the design will occur during 2003, and the manufacturing of the prototypes will occur in 2004 and 2005. The testing of the prototypes will occur in 2006, with any redesign in 2007. The full manufacturing run will be from 2008 until 2012, with units in the field in 2011-2012. Staying on schedule is essential for the timely completion of this project. Following this schedule will allow the team to meet the customer requirements and needs.

Table 3 Programmatic 10 Year Development Schedule

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Contract Start											
Development of Design											
Manufacturing of Prototypes											
Testing of Prototypes											
Redesign											
Full Manufacturing Run											
Units in Field											

2.0 Technical Description of Methods Used

2.1 System Engineering

System Engineering was responsible for ensuring that every component and aspect of the vehicle would work together and stay within the guidelines set by the customer. The following sections describe the guidelines and assumptions made for the vehicle.

The design process utilized an Integrated Product Team (IPT) approach. For example, the mechanical configuration team operated independently from the aerospace team. However, the team works together to optimize the design of the whole vehicle. The primary reason for this type of design is to allow the members to specialize in their assigned area, and to also introduce them into new disciplines. This phase of the design process is the conceptual iterative design. The analysis presented is only the first of many required iterations. Since this is the first step in the long-term design of the vehicle, the calculation and assumptions should not be taken as definite results.

2.1.1 Design Process

Phase 1 – This was the initial stage of the design process. The three teams came together to form one super-team. The teams worked together to derive a baseline design. Each individual was assigned to a discipline and worked in that discipline with the other three teams.

Phase 2 – The teams separate into their individual teams. Each member was assigned a primary discipline of focus. Three different concepts were developed. The team then came together and compared the advantages and disadvantages of each concept to the baseline to pick the best design to refine in phase 3.

Phase 3 – In this phase, the team took the selected concept and started to go into greater detail. Steps were taken to better optimize the design that was chosen for the given criteria that were determined in the CDD.

2.1.2 Overall Guidelines

In order to produce a hybrid vehicle, Hybrids R Us designed The Mole to meet all minimum requirements set forth by the CDD (Appendix A). The team used existing technology because the vehicle must be in production by the year 2012. Throughout the design process it is anticipated that technologies will change and allow for minor changes.

Currently the vehicle is not capable of fully autonomous operation. The team hopes in the future that the technology will be developed so that this feature can be incorporated into the design.

Guidelines:

- Vehicle range of 15–30 km
- Payload of 60 lbs
- Minimum cruise speed of 30 km/h
- Minimum VROC of 200 fpm
- Semi-autonomous nap of the earth maneuvering.

2.1.3 Assumptions

In order to design the vehicle, assumptions were made to begin the iterative process of sizing the engine and power requirements.

- Ground unit will weigh of 400 lbs.
- Ground and air units will have combined weight of 1500 lbs.
- The vehicle will fit in a standard HMMWV trailer.
- Performance of the system will increase as technology increases.
- The ground vehicle will not charge in flight and will have to be charged at the ground station.
- The vehicle will be transportable via a UH-60 helicopter. (Some type of latching device will be adapted to the system for this reason.)

2.2 Aerodynamics

A helicopter works by using a rotor to produce an upward thrust by pushing air in a downward direction through the rotor plane. The column of air moving through the rotor disk produces a stream tube above and below the disk without causing a rotation to occur in the airflow. When the air is pulled downward through the disk the pressure decreases on the top of the rotor. The pressure increases at the rotor and then decreases again on the bottom side of the rotor. The work performed on the air during this process is used to produce the thrust to lift the aircraft (Seddon and Newman, 2001).

The Mole uses a synchropter rotor system to provide the necessary thrust to propel the system. The two separate rotors rotate in opposite directions to each other. This removes the need for a tail rotor reducing the amount of power required for flight.

The following sections explain the aerodynamics that will be used on the Mole.

2.2.1 Trade Study Analysis

The synchropter rotor design was selected for the final concept after a trade study analysis was performed comparing it to a coaxial system. Both systems rely on counter-rotating systems that remove the need for tail rotors. The coaxial system is superior to the synchropter because it does not require a transmission to connect the separate rotors. The synchropter is superior because it will not require as large of a side clearance because the blades are close to the fuselage. It also is exceptionally steady and stable in flight. The synchropter does not fly well at forward velocities over 120 knots but this is not a concern because this is above the desired flight speed given in the CDD.

After listing the pros and cons of each system, a power analysis was performed on each system using the same parameters. This determined the power required to hover and climb and allowed a comparison to determine which system required the least amount of power. Appendix E-1 shows the spreadsheets that were used to perform this comparison. From these results it is shown that the synchropter required less power for hover and climb. The coaxial system had a slightly slower tip velocity and rotor frequency. Table 4, below, summarizes these results.

Table 4 Trade Study Analysis Results

Parameters	Synchropter	Coaxial
P_t (HP)	177	196
V_t (fps)	512	510
f_r (rpm)	815	812

The added weight for an engine to produce over 190 HP negates the slower tip velocities of the coaxial system. The rotor system trade study determined the synchropter to be the best propulsion system for the Mole.

2.2.2 Rotor Design

Several assumptions were needed to begin the design process of the rotor system. Initial conditions were defined to begin the analysis. All were taken from the CDD and are shown in Table 5.

Table 5 Design Parameters

Weight (lbs)	1500
VROC (fpm)	500
Operational Altitude (ft)	4000
Density (lb-sec^2/ft^4)	$2.111\text{x}10^{-3}$

After defining the design parameters, several initial assumptions were required before analysis could begin. These assumptions are shown below in Table 6. The values for C_l, C_{do}, and FM were taken from information provided by Dr. John Berry (Berry 2001). The number of blades was taken from preexisting synchropter helicopter designs. The pitch angle was estimated from a range of pitch values given in Seddon and Newman (Seddon, 2001). All other values were estimated for initial calculations and were later refined.

Table 6 Initial Design Assumptions

Blade Radius (ft)	
Blade Chord (ft)	0.6
Number of Blades per Rotor	2
Overlap Distance (ft)	5
C_l	1.4
Blade Pitch (deg)	9
C_{do}	0.0104
FM	0.8

Using these initial design assumptions, the remainder of the sizing values can be determined. The first of these are three areas: rotor area, overlap area, and total area. The rotor area is the area of the individual rotors, the overlap area is the area of the rotors that will be intermeshing, and the total area is the total surface area of the blades after subtracting the blade overlap area. With the areas known, the remaining preliminary calculations such as the solidity, a measure of the ratio of blade area to disk area, downwash velocity, speed of the air moving downward through the blades, blade area, and blade loading are determined.

With the values explained above, the power requirements for hover and climb were calculated. The helicopter uses two types of power during operation: induced power and profile power. The larger of the two power types is induced power. It is the power that is absorbed by the rotor during hover and the power that produces lift. Profile power is the power required to overcome the drag of the blades. The induced and profile powers were calculated for the design with weights ranging from 0-2000 lbs. These powers were then added to determine the total power required for hover and climb.

The blade tip velocity depends on the area of the blades and the weight of the thrust being produced by the helicopter. This velocity is an important factor in determining how much noise the helicopter will be producing during flight. Tip velocities below 500 ft/sec are considered extremely quiet, and tip velocities above 700 ft/sec are extremely noisy. The tip velocity was calculated for each of the weights used to calculate the required power. After the preliminary tip velocities were determined the blade pitch was adjusted to reduce the tip velocity as much as possible. The rotor frequency was also calculated over a range of weights to be used in the forward flight power requirements. The equations and results for the above calculations are shown in Appendix E-1.

After determining a preliminary range of power requirements, work was done to reduce the power that will be required for flight. An analysis was performed to determine what airfoil would produce the most lift. The best choice was determined to be the NACA 23012 airfoil because of its high lift coefficient and its use on previous helicopter systems. Table 7 shows the airfoil parameters (Anderson, 2001). Adjusting the coefficient of lift and drag parameters for the new airfoil reduced the power requirements. The results of the power analysis at a helicopter weight of 1400 lbs, a rate of climb of 500 fpm, and a rotor radius of 7.2 ft are shown below in Table 8.

Table 7 Airfoil Parameters

Blade Airfoil	NACA 23012
Lift Coefficient	1.557
Maximum Camber	0.15c
Maximum Thickness	12%
Angle of Attack at 0 Lift ($\alpha_{L=0}$)	-1.09°
C_{do}	0.001
C_{mo}	-0.03

Table 8 Finalized Power Requirements

Induced Power (HP)	136
Parasite Power (HP)	0.70
Total Power Required (HP)	137
Rotor Tip Velocity (ft/sec)	417
Rotor Frequency (rpm)	553

After completing the power requirement calculations, research was performed to determine the best blade material. The initial analysis was performed on materials with low densities. Carbon fibers were preferred because of their high strengths and low weights. Several materials were evaluated and RTP Company RTP 2587 Polycarbonate/ABS Alloy (PC/ABS) Carbon Fiber 40%, Table 9, was selected (Mat Web, 2002).

Table 9 Blade Material Parameters

Density (lb/in^3)	0.0506
Tensile Strength (psi)	20,000
Flexural Yield Strength (psi)	28,000
Flexural Modulus (ksi)	2200

2.2.3 Servo Flaps

Servo flaps (Figure 4) are small airfoils located on the trailing edge of the helicopter blades. Push-pull control rods control the flaps. The servo flap is used to adjust the pitch of the blades. This is accomplished by moving the flap in an upward or downward direction that in turn causes the leading edge of the blades to move up or down, respectively. The flaps eliminate the need for a complex and heavy hydraulic control system. The flaps also reduce the amount of vibrations that occur in the blades because of the changing lift. This will cause the entire aircraft to fly smoother better protecting the system avionics and increasing the life span of the entire vehicle. The servo flaps will also help to land the aircraft in the case of an engine failure by automatically increasing the angle of attack that is caused by changes in airflow through the rotors and the decreasing rotor frequencies. This will allow the controller additional time to stabilize a possible descent. (Singh, 2002)

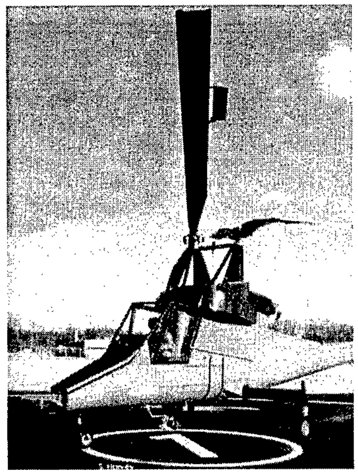


Figure 4 Servo Flaps

2.3 Propulsion and Power

The aim of this study is to evaluate and choose the technologies, that will ensure the propulsion of the UHV by 2012; this concerns the flight configuration, the engine, the clutch and the main gear box. Presented below are the results of this prospect. For each part, the various technologies available are presented along with the decision matrix, the explanation of the decision matrix, and finally the diagram of convergence.

2.3.1 Flight Configuration

For the Baseline Review a transmission close to a helicopter configuration was chosen because of the mission profile. Since it has to land on an unprepared area; the best solution was a vehicle that would fly like a helicopter. To reduce the size of the transmission, the first concept for the baseline review was a coaxial rotor.

For the alternative review three different systems were studied:

First concept:	two flapping rotors
Second concept:	four tilt rotors
Third concept:	V rotor

Flapping rotors is a new concept in rotor design recently proposed by Dr Vladimir Savov. Rotors propel up and down the mast to make the blades rotate like an autogiro.

The four tilt rotor concept uses a tilt rotor system. The design achieves redundancy via four inducted fans. This increases the overall survivability of the system. The tilt rotor performs a conversion of VTOL aircraft into a more ordinary aircraft by tilting the propeller from vertical to horizontal to achieve horizontal flight.

The V rotor design utilizes synchropter rotors. The two drive shaft rotors make an angle between them. This design enhances the point-to-point flight endurance of the aircraft.

Table 10 is a decision matrix comparing the three rotor designs. The most important factor in the choice of engines is the weight. Next the team considered the volume in order to respect the small size imposed by the CDD: the UHV must be carried on a HMMWV trailer. Moreover, the vehicle had to be reliable: priority is given to mission completion. Finally, the system must provide as little noise as possible to perform a successful mission.

Table 10 Rotor Evaluation Matrix

Parameters	Coefficient	Flapping rotor	Tilt rotor	V rotor
Noise level	1	-	-	+
Reliability	2	--	-	+
Weight	3	-	--	+
Volume	2	-	-	+
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

2.3.2 The Engine

From the beginning until the Final Review, several searches for different kinds of engines, including turbines, fuel cells and piston engines were performed. Engines researched were engines which exist today or whose development will be ready for the industrial phase of our UHV for deployment on a battlefield in 2012. In that way, all other exotic means of propulsion, such as ionic propulsion, etc., were excluded. Benefits of the diesel-cycle engine are included in Table 11. Table 12 and Figure 5 compare three engine types. Table 13 is a decision matrix showing the diesel engine as the best choice.

Table 11 Benefits of the Diesel-Cycle Engine

Desirable Fuel Type	Low flammability and worldwide availability of Jet-A or diesel fuel is valued in all applications; current aviation fuel for high compression engines is leaded and will eventually be made unavailable by the EPA (Environmental Protection Agency), making those engines unusable.
Fuel Efficiency	Diesel engine is designed to BSFC (brake specific fuel consumption) near 0.35 lb/hp/hr versus current avgas-powered aviation engine book BSFC near 0.59 lb/hp/hr at 75% and above.
Lower Fuel Cost	20-30% more range per gallon. Also, the cost per gallon of Jet A1 averages is $0.09 less than 100 LL aviation fuel in the U.S.
Electromagnetic Noise Elimination	Absence of an ignition system reduces interference with navigational and communication systems; for military applications, this is desirable for tactical reasons.
Simplicity of Operation	Single-lever power operation (no mixture control).
Durability	Inherent in diesels because diesel and jet fuels provide more lubricity and because no electrical system (magnetos or electronic ignition) is required.

Table 12 Engine Comparison Table

	Fuel Cell	APU	Diesel engine	Rotary engine
Noise at 7m (dB)	40-60	100	>60 ; <100	>60 ; <100
Ratio power/weight (kW/kg)	0.15	4*	1.3	2 – 2.5
Efficiency (%)	35	20 - 25	35 – 40	-
BSFC (kg/kW/h)	0.21	0.6	0.21	0.32
TBO (hours)	-	+10 000	2000	50 – 1500

* without engine reducer

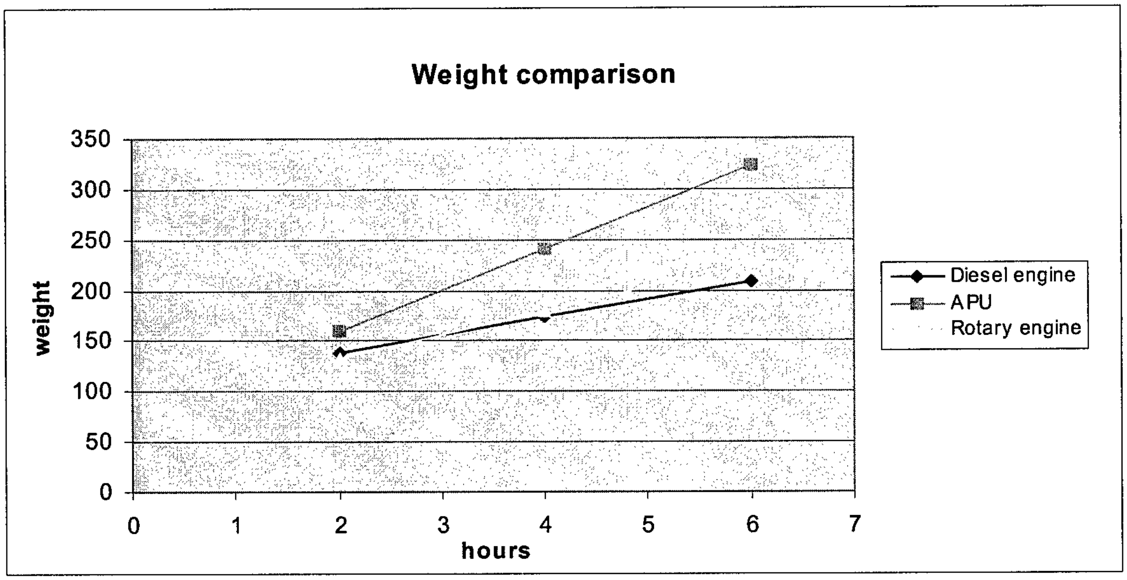


Figure 5 Engine Weight Comparison

According to the CDD, more importance was given to certain characteristics of the UHV: weight, reliability, noise and volume.

Table 13 Engine Evaluation Matrix

	Coefficient	Fuel Cell	APU	Diesel	Rotary
Noise level	2	++	--	+	+
Reliability	3	+	++	+	-
Weight	3	-	--	+	+
Volume	1	X	++	+	+

Note: the mark 'X' is an eliminatory note: at this time fuel cells are too bulky to be used in a UHV.

The choice of a diesel engine leads to the Zoche engine. This is a German engine, which presents the best characteristics to meet the CDD requirements. Specifications for the Zoche engine are located in Table14.

Table 14 Zoche Engine Specifications

Power at 2500 rpm	110 kW (150 hp)
Height	.555 m (21.8 in)
Width	.555 m (21.8 in)
Diameter Including Cooling Ducts	.648m (25.5 in)
Length	.725 m (28.5 in)
Weight*	84 kg (185 lbs)
Max Power BSFC	225 g/kWh (.365 lb/hp hr)
Cruise (75%) BSFC	212 g/kWh (.346 lb/hp hr)
Cruise (75%) Consumption	21.1 l/hr (5.57 gal/hr)
Fuels	Diesel Fuel #2, Jet Fuel JP 4, JP 5, JP 8, Jet A

*Weight includes: Pneumatic starter, alternator (3 kW, 24 V), hydraulic prop-governor, turbo- and supercharger, oil and fuel-filter.

2.3.3 Clutch

The use of a clutch is necessary according to the configuration of this system.
It is required both for the starting of the engine and in case of an engine stop (so as to disengage the engine shaft from the rotor shaft). Clutches are useful devices with two rotating shafts. In these devices, one of the shafts is typically driven by a motor or pulley, and the other shaft is driving another device. In a drill for instance, one shaft is driven by a motor, and the other is driving a drill chuck. The clutch connects the two shafts so that they can either be locked together and spin at the same speed, or they can be decoupled and spin at different speeds.

Three kinds of clutches were studied which will be able to meet the requirements of the CDD: the magnetic, the multi-plates and centrifugal clutches.

Magnetic clutches are like mechanical clutches with two spins, but the control is not mechanical. It is an electrical order by coils which create a magnetic field that engages the clutch. In that case, the coils need to be supplied with continuous current obtained through the engine alternator; this one delivers an alternative current which has to be transformed to continuous current using a transformer.

The multi-plates clutch is a classic clutch. Multi-plates slip clutches were studied because the torque to transmit (42daN/m) is too large to use only one plate. In this case, the clutching is realized with the help of an engine pump which delivers the required pressure using a hydraulic circuit. The disadvantage of this kind of clutch is that it requires taking some power from the engine, because of the pump, to make the clutch work. Moreover, this technology brings a complexity of an hydraulic circuit.

The centrifugal clutches are the most common clutches in use within the helicopter industry. The principle is simple: This clutch is constituted by a drum on which hoofs, dragged by the force centrifuge from a shaft, rub on its outer surface. The hoofs and the drum contact when the centrifuge force is great enough. This contact is performed by the use of an abrasive product like “Ferrodo.” Then, the drum is dragged and transmits the rotational motion from the hoof shaft. When the engine stops, the force centrifuge decreases and the hoofs are dragged back toward the center of the clutch through a spring or an assembly of elastic washers (Belleville washers). The advantages of such a clutch, in comparison with the other kinds, are: its weight and volume and its higher reliability due to a smaller technical complexity. It is dense, simple and sturdy. It does not require any electrical alimentation or hydraulic command with all the components and failure risks those imply. Finally, it is a well-proven technology in the helicopter industry.

Decision matrix: Priority was given first to reliability, then to weight and radar discretion, as they are both important. Table 15 compares the three clutches.

Table 15 Clutch Evaluation Matrix

Parameters	Coefficient	Magnetic	Multi-plates	Centrifugal
Radar-discretion	1	-	+	+
Weight	1	+	-	++
Reliability	2	++	-	+
CHOICE		4	-2	6

According to the decision matrix, it appears that the centrifugal clutch is the best clutch for the requirements.

2.3.4 Transmission

The transmission using pulleys can be done with a chain or with an elastomer belt. Pulleys and belts allow the transmission a movement of rotation of a leading shaft to a lead shaft relatively far away. The transmission of the movement is possible whatever the direction of rotation. However the median plan of every belt stalk must be positioned in the pulley median plan.

By knowing our engine torque as well as our engine speed of rotation, it is easy to calculate the power that the pulley has to pass on. In this case, the power to supply is about 110 kW. Only 15 belts are needed; each can spend 7.5 kW with a step of 12.7 mm between every tooth. This represents a rather large congestion, considering that our vehicle has to be as compact as possible.

Another means to pass on the movement of rotation is to use gearings, either straight teeth or helical teeth. The gearwheels with straight teeth have the advantage to keep the torque: the efficiency is 99%, but is a little noisier than helical teeth. On the other hand, these gears are subjected to large stresses around the teeth. The other possibility is a main transmission gear box using the helical teeth. They are quieter than the straight teeth. Furthermore with this type of teeth we have more teeth on contact, hence less stresses in the gearings. However, the efficiency is near 95%.

If the engine rotation speed is too high, it can be necessary to place a reducer after the output shaft. Reducers used in the helicopter industry, often use an epicyclical gear with straight teeth. The efficiency ratio reaches 99%.

This kind of reducer is used on an automatic gearbox and can have various reduction ratios. However, in this case, the engine rotates at 2500 rpm and we need a rotation of 815 rpm for the rotors. This implies a reduction of 3, which is not enough to use an epicyclical gear. An epicyclical gear must have from 6 to 9 satellites for this reducing ratio, which implies an large increase of weight.

The decision matrix for the transmission is shown in Table 16.

First, the most important thing is the reliability; it is a key component. The survivability of the UHV depends on the functioning of the main gearbox. Second, the main gearbox must contribute to the global effort of weight and volume reduction to fit the CDD requirements. Finally, less importance was given to the noise, as it is an internal component, whose noise is drowned outside by the rotor's noise. The epicyclical gear was not considered because it is useful only for higher speed ratios. If the engine had a higher speed of rotation, one or two levels of epicyclical gear would have been used.

Concerning the noise, a pulley with a chain or an elastomer belt is less noisy than a gearbox, which uses straight or helical teeth. Moreover, a pulley system is lighter than a gearing system. However, it is much more voluminous. Besides, the reliability of a pulley system is less important than a gearing's system:

- TBO of a pulley system with belt is near 500 hours
- TBO of a gearing system is near 2500 to 3000 hours

Table 16 Evaluation Matrix

Parameter	Coefficient	Pulley	Straight teeth	Helical teeth
Noise	1	++	-	+
Weight	2	++	+	+
Volume	2	-	++	++
Reliability	3	--	+	+

According to the decision matrix, it appears that a helical gearings system is the best solution for the mission profile. A classical gearing system will be used and not an epicyclical gear because of its weight.

In that case it will have only three engaged gearings between the clutch and a rotor shaft. They must still be sized to obtain the needed reduction ratio of 3. It was decided to do the reduction two times: the first one just after the clutch (r = 2.5) and a second on the rotor larger diameter, and a larger bulk of the main gearbox.

Calculations were made to estimate the size of the main gearbox. The following dimensions were obtained: Length: 270 mm, Width: 150 mm, Height: 150 mm.

Note: To decrease the transmission weight it is possible to use hollow shaft. Their sizes are realized according to their acceptable stresses.

For The Mole, a freewheel is required to prevent the rotational motion of the rotor from a brutal stop in the case of an engine or clutch break. It is best placed as close as possible to the rotors to protect it from all the possible mechanical failure which could occur between the engine and the rotors. Traditionally, it is placed just behind the engine and the clutch, i.e.

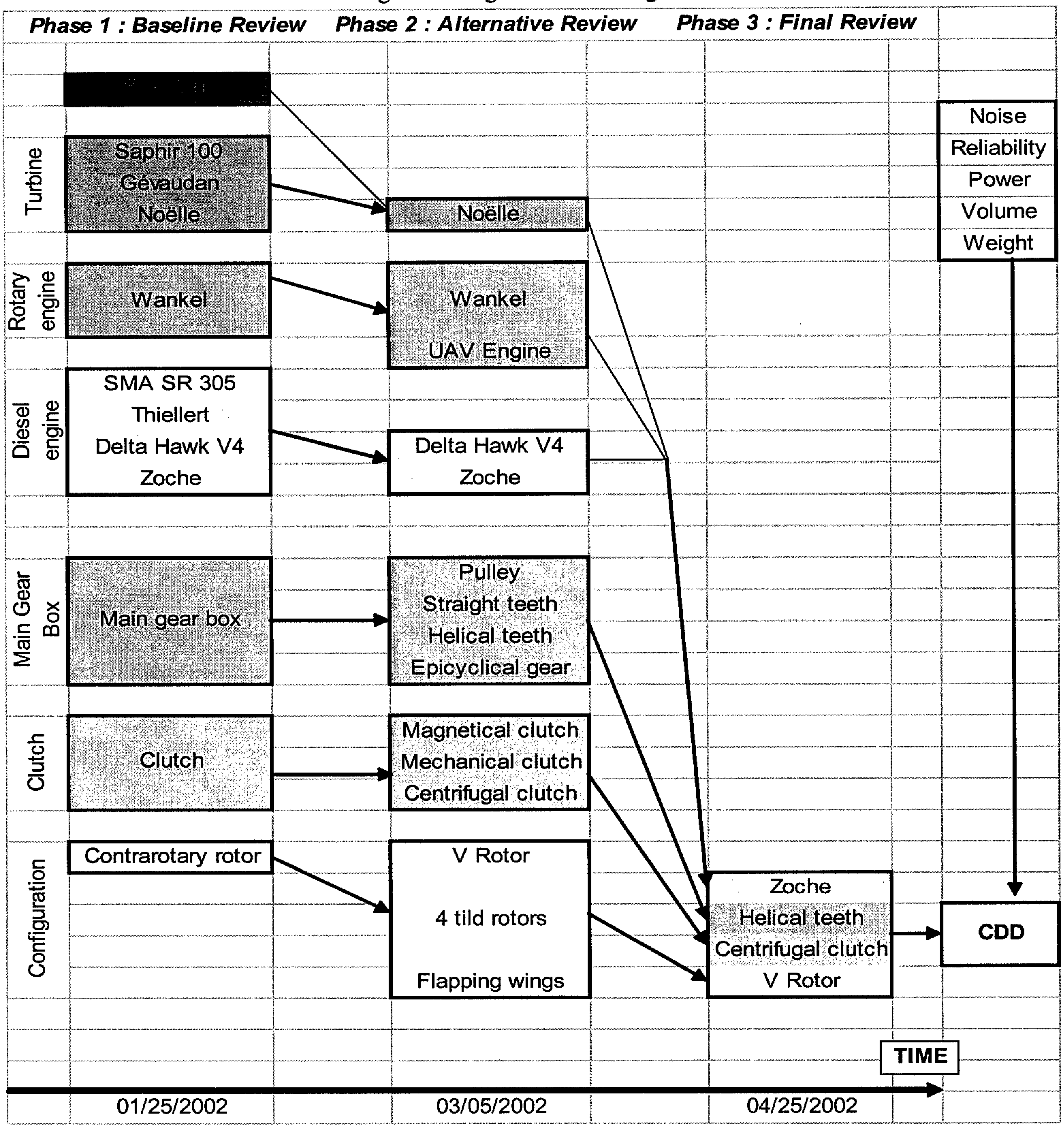
behind the less reliable components. In this case, we will place it behind the main gearbox, between the two rotor shafts, which will increase the reliability of the propulsion system.

Freewheels are directional couplings, which means that the driving member rotates the driven member in one direction, while automatically disengaging itself from the driven part when the direction of rotation is reversed. The two operating states are: Transmission of torque and Idling (Overrunning).

The freewheel disengages automatically when the driven member rotates faster than the driving member, in the case of an engine stop, to allow autorotation. Two basic versions are available. The overrunning speed determines the selection of the appropriate model: Various types, with and without bearings, are available. In addition, the freewheel system, with various flanges, covers and flexible couplings, offers a wide range of possible combinations.

Final diagram of convergence is shown in Figure 6.

Figure 6 Diagram of Convergence



2.4 Noise Reduction

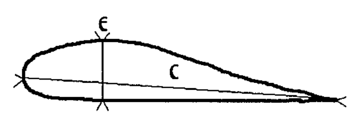
A "near quiet acoustic signature" is required for the UHV according to the CDD. The most significant source of noise is the rotor blades. They produce low frequency with high sound pressure level. These two characteristics imply a large propagation of noise in the environment, which is critical for a military mission. Blades produce two types of noise during specific stages of flight: The BRI (Blade Rotor Interaction) is created during low speed descent or UHV maneuver, and the HSI (High Speed Impulsive noise) appears during high speed displacement.

Bi-rotors and mono-rotos produce approximately the same level of sound. The speed of a blade must not be higher than Mach 0.6 because of problems of vibrations and stability of flight. Most of the noise is produced by the blade tip in a cone of 45° in front of our UHV. It is during the take off and landing phases that the noise is the most significant. Landing is significant because of the interaction with the vortex created by the previous blade. Take off is significant because the maximum power is needed (much noisier).

Research has provided different kinds of noise reduction systems which are currently in use or only in experimentation. It is possible to reduce the noise emissions coming from the rotor by optimizing the blade aerodynamics; several different ways are possible.

Profile thickness: the blades have to be as thin as possible on its tip to reduce the emitted noise: the ratio e/c has to be close to 7% (and 10 to 15% at the other extremity to be able to transmit the forces), as shown in Figure 7.

Figure 7 Profile Thickness



The higher the speed, the higher the noise the blades will generate..

At this time, the most used and efficient way to reduce rotor noise is through modifying blade shape, especially the shape of the blade's tip. Helicopter firms have studied blade shapes and developed their own shapes, especially for the tip. The current form is a blade with a round tip. This solution decreases vortex and is very reliable. But, at the same time this static system is not optimized for each stage of the flight and has no real future improvement prospects.

2.4.1 Active Noise Control

A new approach to noise reduction is the active noise control (ANC) effort. The primary principle of active noise control is to sense the noise disturbances in the engine and cancel them before they leave the engine. In effect, negative noise is made to cancel out the engine's sound waves so that no noise is heard. This is a multidisciplinary effort involving duct acoustics, controls, and actuator/sensor design.

To date, several concepts have shown successful cancellation of selected acoustic modes. Because noise is the sum of all possible acoustic modes, this effort is still in its infancy, but it has potentially high payoffs.

Basic knowledge: two vibrations created in total phase opposition and pointed in the same direction eliminate themselves and there is no sound in result. This is the theory which is used in this system. In fact, noise would be analyzed and the engine would produce a vibration, which is the opposite of real noise, in order to eliminate it.

The efficiency of such a system is very good (already used in the automobile industry with success) and studies on it show a decrease of noise between 15 and 30 dB on low frequencies. This system needs a real time calculator but its energy consumption and volume are quite small. But this complex control system needs a high speed processor. The most important weakness of the ANC is that it is really difficult to recreate exactly the sound of a rotor and to point in the same direction (lots of source needed, external influence, high level sound, etc.). In that way, the ANC is more adapted to canceling the internal noise, as in the exhaust of an engine or inside a helicopter cabin for the passenger accommodations.

This is an efficient system for closed rooms, and low frequencies, so it might be used for the acoustic protection of avionics (interior of the UHV) and cancellation of noise produced by the main gearbox. However, it is not efficient enough to reduce sufficiently the noise created by the rotors, as this is a multidirectional noise.

2.4.2 Higher Harmonic Control

The aim is to create blade oscillations at each round in order to displace and deform the tip vortex and finally to reduce the noise produced by the interaction blade/vortex. In fact, this system decreases BRI sounds. This motion can be created using two different methods: a mechanical system on the rotor and a piezoelectric system placed into the blades.

The mechanical system: This system consists of a cyclic tray active piloting: this is realized through a command using sinusoidal functions, which are introduced on the high harmonics of the rotor noise. It can control the blade trajectory and position in relation to those of the vortex (created by the previous blade in descent or ascent). This system is reliable and easier to change but it doesn't allow describing the entire frequency spectrum and a compromise must be made between vibrations and noise control.

The piezoelectric system: It consists in the introduction of piezoelectric materials into the blades. There are light semi-mechanical systems, which have a lot of possibilities for development. It allows having swing-wing blades: by modifying the curve of the blade, this system can control at the same time vibrations of the structure and blade noise.

2.5 Ground Robotics/Vehicle

2.5.1 Ground System Overview

The ground system for The Mole utilizes a three-wheel, V-shaped system, powered by two electric motors, one on each back wheel. Due to weight considerations, a motor on the front wheel was eliminated. A system consisting of one motor used to power all three wheels was also considered. Adding a subsystem consisting of a transmission/differential and the components needed to distribute power to each wheel, weight became a serious issue. An advantage of the two-motor system is that it allows the ground vehicle to steer itself. Using a technology known as skid steering, by holding one wheel stationary and moving the other wheel a turning motion can be generated. This could not have been achieved using one motor, since both wheels would always maintain the same speed. Because The Mole is a two-piece vehicle, the ground vehicle does not have the added weight of the flight vehicle to adjust for in considering ground performance.

2.5.2 Power Required Calculations

The following calculations located in table 17 were made to determine the design of the electrical motors.

Table 17 Calculations To Determine the Design of the Electrical Motors

Maximum Speed	$v_g = 6$ km/h (5.47 ft/s)
The Mole Weight	m = 136 kg (300 lbf)
Maximum acceleration	1 m/s^2
Maximum slope	$\alpha = 12^o$
Motor wheel diameter	$d_w = 25.4$cm (10 in.)
Gravity	$g = 9.81 m/s^2$
Rotational Speed	Equation 1: $S = \pi d_w = 79.85cm = 31.43in$
	Equation 2: $n = (v * 60 * 12)/S = 125.31rpm$
Maximum Torque (C_{max})	Equation 3: $ma = -mg\sin(\alpha) + 2C_{max}/d$
	Equation 4: $C_{max} = d(ma + mg\sin(\alpha))/2$
	Equation 5: $C_{max} = 52.5$ N*m
Maximum Power Required	Equation 6: $P=FV=(mg)v_g1000)/(4.45-3600-.3048) = 1639.4$ ft-lb/s = 2.98 hp

Values for power required as a function of velocity can be seen below in Table 18.

Table 18 Power Required Vs Velocity

Velocity (km/hr)	Velocity (ft/s)	Power (hp)
0	0.00	0.00
0.5	0.46	0.25
1	0.91	0.50
1.5	1.37	0.75
2	1.82	0.99
2.5	2.28	1.24
3	2.73	1.49
3.5	3.19	1.74
4	3.65	1.99
4.5	4.10	2.24
5	4.56	2.49
5.5	5.01	2.73
6	5.47	2.98

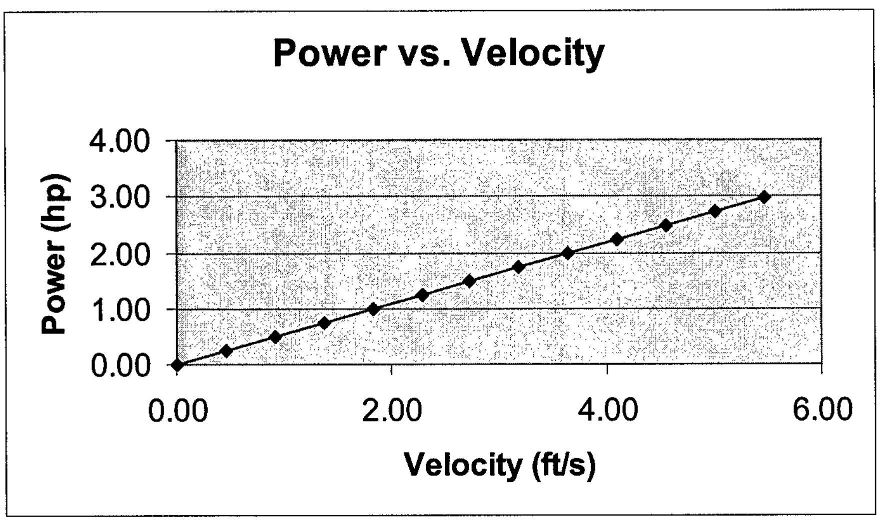


Figure 8 Power Vs Forward Velocity

Figure 8, is a plot of power required vs. velocity that illustrates a linear relation between the two.

After comparing electrical motors on the web (Emotorstore, 2002), two motors were chosen with the following specifications each:

- Max Rotation Speed: 3300 rpm
- Max Torque: 13.2 N*m
- Motor Weight: 8.5 N
- Total Power Required: 2.2 kW

2.5.3 Ground Robotics Mass Definition

The combined weight of the electric motors is approximately 17 N (76 lbs). This number was obtained by comparing various motors used for small ground vehicles such as golf carts. The dimensions for the wheels are eight inches in diameter for the two rear wheels, and ten inches in diameter for the front wheel. The wheels are made of aluminum and have an approximate weight of eight N (35 lbs). Using the above components, the total weight of the ground robotics system is 25 N (111 lbs). A total weight of approximately 30 N (135 lbs) is realized, for additional elements and attachment hardware.

2.6 Mechanical Configuration/ Structures

2.6.1 Weight

Weight is a major issue while designing the vehicle. By setting the weight limit for the system at 1500 lbs, the component selection had to consider weight. Table 19 is a weight breakdown for seven different categories of components.

Table 19 IPT Weight Breakdown Categories (units in lbs)

UHV	-	-	-	-
1. Air drive system:		-	-	-
o engine/motor	185			
o transmission	40			
o rotors	175			
o other	15			
- **Subtotal**		415	-	-
2. Ground Drive system	-	-	-	-
o batteries/ fuel cells	138			
o motors	73			
o mode (treads/wheels),	30			
o other	10			
- **Subtotal**		251	-	-
3. Avionics and Sensor weight	-	-	-	-
o avionics	134			
o sensors	62			
o power sources	40			
o other	10	-	-	-
- **Subtotal**		246	-	-
4. Structural Weight	-	-	-	-
o frame	40			
o skin	35			
o other	20			
- **subtotal**	-	95	-	-
5. UHV Subtotal	-	-	1007	-
o Weight Contingency (20%)		201	-	-
UHV DRY WEIGHT	-	-		**1208**
6. Mission-Dependent Weights (max)	-	-	-	-
o Max Payload Weight	60			
o Max Optional Sensors	40			
o Max Fuel Load	79			
- **Subtotal**	-	179	-	-
UHV MAX GROSS TAKEOFF WEIGHT	-	-	-	**1387**
7. Support and Handling Equipment	-	-	-	-
o Ground Station				
o Shipping Container/ Palate/straps				
o Test and Measurement Equipment				
o Spare Parts /Tools				
o Additional Mission-Dependent Sensors				
- **Subtotal**	-	100	-	-
UHV SYSTEM SHIPPING WEIGHT	-	-	-	**1487**
	-	-	-	

2.6.2 Payload Handling

2.6.2.1 Payload Location

The payload will be located in the center of gravity on the ground unit. The reason for this is so The Mole can operate with or without the payload. If the payload is located somewhere other than the center of gravity the flight characteristics of the vehicle will change with the payload.

2.6.2.2 Payload Specifications

- The payload can be no larger than 2'x2'x2' box. This limitation was set by the CDD.
- The payload can weigh up to 60 pounds.
- The payload will be unloaded and loaded with the help of the ground motors. The motors will have a clutch system that can disengage the wheels and engage the latch and pulley system in the ground unit.
- The payload will have to have its own power supply if the payload requires it.
- It will be protected from the outside environment only by the skin of the ground unit.

2.6.3 Material Overview

The choice of material was very important because of the weight issue. The materials needed are those that have excellent mechanical properties, while also being very lightweight. The primary materials used are located in Table 20.

Table 20 Primary Materials

Component	Material	Benefits
Frame	Titanium	Lightweight and Strong
Skin	Beryllium-Aluminum Alloy	Lightweight and Strong
Tire Material	Vinyl	Durable and inexpensive
Wheels	PTS Grade Fiber Reinforced Plastic	Lightweight/Durable
Rotors	Carbon Fiber AS4C	Lightweight and Strong

Refer to Appendix E-2 for Material Specification.

2.6.4 Ground Unit Configuration

The ground unit is configured for maneuverability and flexibility. It will be the unit that carries the payload. The payload will be placed in the center of the unit and will be accessible through a door on the side of the unit. It will have latch and pulley system that will unload and load the payload. It will also have a biochemical detection system that can relay information back to the air unit for storage or immediate relaying back to the base. It will also have the capabilities to send images the same way the biochemical system does. It will steer using the back two wheels turning at different speeds. There will only be three wheels on the unit. The center of gravity is located in the center of the payload. All components are placed to maintain stability while the unit is in flight with the air unit.

2.6.5 Air Unit Configuration

The overall configuration of the air unit is one that allows the maximum flexibility and survivability in the field. The motor is located directly under the rotors to help in the center of gravity and also the simplicity of the gearing system. The fuel tank is located directly in the center of gravity to insure that as the vehicle consumes fuel it will not upset the balance of the entire aircraft. The camera will be located on the tip of the nose for better vision. The avionics are located near the back to offset the biochemical system that is located at the front of the aircraft. The ground unit will enter from the back of the plane. The reason for this is to insure that the ground unit will not interfere with the camera on the nose of the aircraft. The ground unit will be latched in under the plane until deployment and enter and exit from the rear of the plane. All the components are placed in the vehicle based on center of gravity to maintain stability.

The air unit will also have sling latches located on the top of the aircraft. They will be located at the four corners of the unit. Locating them at the corners will make the vehicle more stable during flight.

2.7 Avionics/Flight Controls

The Mole must incorporate a significant amount of sensing and processing hardware in order to provide for nearly autonomous mission completion and to ensure that the system is a versatile and robust platform for a wide range of surveillance and reconnaissance applications. The two vehicles that comprise The Mole – the aerial and ground vehicles – are each capable of internal sensing, navigation, and communication to an extent appropriate for their mission profiles.

The Mole is designed to be "nearly-autonomous." Software, designed to run on a field-grade laptop, allows for pre-mission planning and simulation before uploading to The Mole's flight computer. During the mission, a single operator may use this terminal to view real-time mission data or modify the mission profile. However, The Mole does not support fly-by-wire operation. Hybrids R Us believes that fly-by-wire operation is not an essential capability, as it would increase the complexity of the ground station and introduce control problems due to communications latency if The Mole were communicating exclusively BLOS. The ground terminal software communicates with The Mole through a Common Data Link based MIST (Modular Interoperable Surface Terminal) or something similar.

2.7.1 Aerial Vehicle

The Mole's flight control is provided by an integrated avionics subsystem which incorporates most basic navigational functions and provides control outputs. The Mole is capable of navigating a pre-programmed set of waypoints using GPS. The Mole's central processing unit has the capability of either loading and following pre-created terrain maps, or of following unmapped terrain using a unique vision-based terrain-following system. The aerial vehicle houses the primary long-range communication components, which provide both LOS radio and BLOS satellite relay capability. Low-power, short-range communications capability is included so that the aerial vehicle may act as the control and relay center for the ground vehicle during its mission. The aerial vehicle also incorporates a package for the detection and identification of airborne biological and chemical agents. The sensors and processing units which exchange data and control signals do so using interfaces suited to their bandwidth requirements. Recognized standard interfaces such as RS-232 and MIL-1553B are used whenever possible.

2.7.1.1 Avionics and Navigation

The Mole contains three main computers: the MIAG (Modular Integrated Avionics Group), the RVM (Reconfigurable Vision Machine) and the Flight Control computer.

The heart of The Mole's avionics system is the MIAG (Modular Integrated Avionics Group). The MIAG is a complete management system specifically for use in UAV's which incorporates a DGPS-capable Global Positioning receiver, a fiber optic inertial measurement unit, local air data pressure transducers, and an IFF transponder. The MIAG is capable of exchanging data with the flight computer as well as providing outputs for engine control and steering.

Two MicroSTAR FLIR cameras are capable of capturing data using dual imaging sensors – high resolution infrared and boresighted CCD-TV with low-light capability. Their lightweight and compact design translates into saved fuel, minimized drag, increased mission duration, and improved weight and balance calculations (MicroSTAR, March 2002).

The Mole is able to follow terrain either by matching its current GPS-provided location with terrain data from a loadable map, or by using its twin FLIR/CCD imagers with the Reconfigurable Vision Machine (RVM) vision-based terrain following system. The RVM is a flexible and modular computer vision architecture. This system is in existence today and is a very powerful platform that is capable of performing a wide variety of tasks. The RVM has the dedicated, real-time performance and data transfer bandwidth needed to guarantee vision results at the required rate (Reconfigurable, March 2002).

The Flight Computer is the control center for all communications and sensor processing. It accepts inputs from the Aerial and Ground Vehicles, the MIAG, the RVM, and the ground station. It processes all inputs and sends pertinent information to the other computers allowing them to adjust for obstacles and unplanned problems. It also transmits information to the ground station through a direct link and via satellite uplink. Main communication links are shown in Figure 9. Figure 10 is a sample image from FLIR/CCD images.

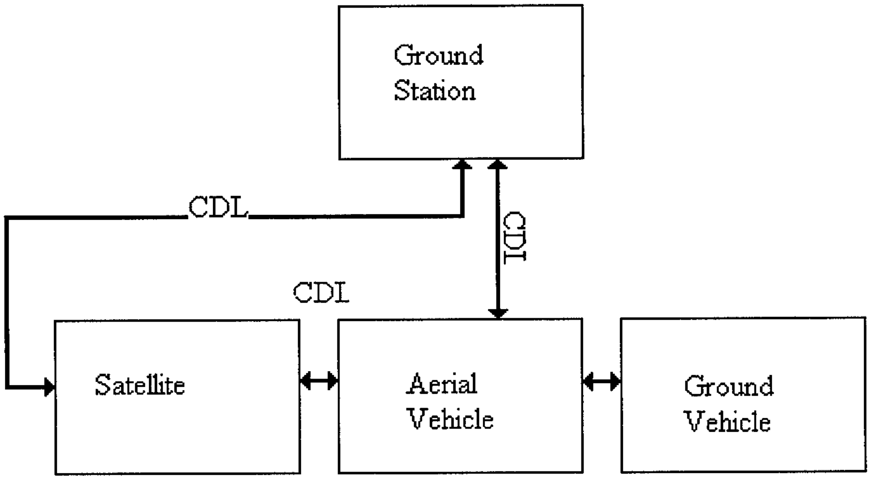


Figure 9 Main Communication Links

The Mole also utilizes a miniature radar altimeter which provides a constant altitude-above-ground measurement up to 700 m (approximately 2300 ft) as an augmentation and backup to the vision-based system.

2.7.1.2 Sensing and Communication

In addition to ground tracking and terrain following, the RVM runs algorithms for object detection, object tracking, and localization. Its modular design also allows it to be upgradeable to meet future challenges and to take advantage of the new technologies that are continuously becoming available. The dual cameras are mounted on swivel turrets and may be aimed from the remote ground station when they are not being used for automated tracking.

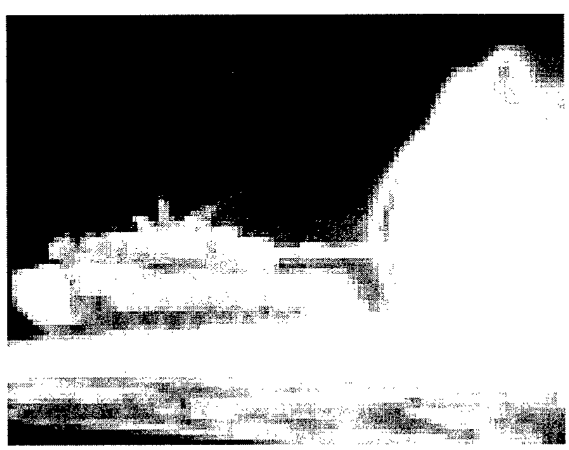


Figure 10 Sample Image From FLIR/CCD (FLIR-tank firing)

A chemical and biological agent detection package is installed in the aerial vehicle. This package was specified by the customer and is capable of detecting the presence and type of airborne chemical and biological contaminants. This package is connected to the central processing unit so that it may relay data in real time to personnel on the ground.

The Mole communicates with its ground station using secure CDL (Common Data Link) transmitters. Hybrids R Us has chosen CDL because of its position as an emerging high-bandwidth standard for secure data communications with unmanned aerial vehicles. CDL provides a wide range of operating modes, both LOS and BLOS, to meet the requirements of present and future missions. Currently, The Mole is designed to support CDL Class I for LOS communication and CDL Class IV and V for satellite relay BLOS.

2.7.2 Ground Vehicle

The Mole's ground vehicle incorporates its own independent sensors and processors, although they are of reduced complexity compared to the aerial vehicle. The ground vehicle incorporates a GPS receiver so that it may follow a pre-programmed route and re-trace that route to return to the aerial vehicle if necessary. The ground vehicle's key capabilities include autonomous navigation, chemical and biological agent detection, and video relay. One of Hybrids R Us's design goals was to minimize cost and complexity of the ground vehicle so that it could be somewhat expendable (for example, if it were seen and destroyed, or if it detected a biological contaminant).

The ground vehicle uses low-power transmitters to communicate with the aerial vehicle and report its location and status. The aerial vehicle's main computers may be configured to relay the ground vehicle's information to a base station in real time or simply to record specific information for later download at the base station operator's request.

A small chemical and biological detection subsystem known as Lab-On-A-Chip is being developed at Sandia National Laboratories. To help minimize size and weight, an implementation of this system is included in the ground vehicle to analyze the surroundings for airborne biological or chemical agents. At this time, the Sandia system is not able to identify as wide a range of contaminants as the system used in the aerial vehicle; however, development is continually advancing and we expect the Lab-On-A-Chip technology to improve quickly.

The ground vehicle's "eye" is a single, small camera in the nose of the vehicle. This camera is to be used for image capture and relay only. It may include a visible or IR illuminator for use at night or in low light environments.

For navigation, the ground vehicle relies on GPS. The GPS system is augmented by infrared proximity sensors mounted on the front corners of the vehicle to provide for basic obstacle avoidance.

The ground vehicle incorporates a general-purpose central processing unit to accept GPS data and control signals from the aerial vehicle, process sensor data, control vehicle speed and steering, and relay information to the aerial vehicle.

2.8 Mission Simulation

The proposed design has been simulated against several operating scenarios in order to assess the design's performance in multiple applications. The first simulation was completed in order to predict how well the design would perform when employed against the basic mission profile as described by the customer in the CDD. Other simulations were performed as a basis of substantiating the design's application for other scenarios. All of the graphs or figures that are mentioned in this section are included in Appendix E-4 of this report. The simulations described in this report assume that the Total Takeoff Weight is 1400 lbs; the VROC is 500 fpm; the fuel is 10 US gallons of Diesel Fuel Grade 2; flight speed is at the estimated most economical; and the ground vehicle weighs 200 lbs.

2.8.1 Most Economic Flight Speed

A graph of the required power versus the forward flight speed was generated in Microsoft Excel in order to graphically estimate the most economic flight speed. The graph is included in this report in Appendix E4 as Figure E4-1. The Aerodynamics team supplied the required power values for the graph, which indicates that the most economic flight speed is approximately 72 km/hr. This speed was used in all subsequent simulations.

2.8.2 Basic Mission Profile

A simulation of the basic mission profile was conducted using a forward flight speed of 72 km/hr. The Propulsion team supplied the specification sheet for the engine. The specification sheet indicates that the engine is a multi-alternative fuel engine. The engine will operate on #2 Diesel fuel, Jet Fuel JP 4, JP 5, JP 8, or Jet A. The fuel consumption is listed as follows:

FC = 0.365 lbs/hph (5.57 gal/h) at 75% Power

The specification does not indicate which fuel that the fuel consumption rates apply to. The numbers were manipulated mathematically and the density of the unknown fuel was determined to be approximately 7.4 lbs/US gallon. The density of Diesel Fuel #2 was conservatively estimated at 7.9 lbs/US gallon (Bell, 04-18-02). The calculations were based on a fuel consumption of 5.57 gal/hr at 75% MRP. Table E4-1 in Appendix E4 shows a breakout of the fuel consumption rates for the basic mission. The table indicates that 6 gallons of fuel would be adequate for the specified mission profile. NOE flight conditions were taken into consideration by doubling the forward flight distance. A 10% fuel reserve was added to the required fuel and the NOE conditions. The actual fuel tank was sized for a 10-gallon fuel capacity. The actual fuel reserve with this design is estimated at 67%. This exceeds the 10% required by the CDD.

2.8.3 Other Simulations

Other simulations were performed for the aircraft both with and without the ground vehicle attachment. Tables 21 and 22 summarize the results of the simulations. The simulation spreadsheets have been included in this report in Appendix C3.

Table 21 Flight Endurance Simulations

Simulation Description	Endurance (km)	Endurance (hrs)	Total Fuel (gal)
Point to point flight endurance (with ground vehicle)	340	4.83	9.9
Point to point flight endurance (without ground vehicle)	425	6.01	9.9

Table 22 Other Simulations

Simulation Description	Time to Redock (min)	Total Fuel (gal)
Redocking from Hover; Retrieval Flight Full Fuel Supply	50	9.97
Redocking from Hover; NOE; Retrival Flight Full Fuel	40	10.00
Redocking from Hover; Retrieval Flight without refueling	30	9.01

2.8.4 Ground Segment Simulations

The ground mission is powered by four 12-volt batteries. The batteries supply the electric motors and the sensors that are utilized during the ground mission segment. The electric motors selected by the Ground Robotics team require 36 Volts and 62 Amps. This simulation was based on using three of the 12-volt batteries in a series combination in order to supply the 36-volts required by the motors.

The Ground Robotics team supplied the specification data for the Optima batteries that were selected. The data indicates that the AMP*HR rating for the batteries is 55 amps at a 20-hour duration. The data did not include a performance curve for the characteristics of the battery at different amperage loadings. The data indicates that the batteries can be safely discharged to a voltage of 10.2 volts without damaging the batteries.

A basic voltage decay equation was used to generate performance curves for the selected batteries (Holman, J.P. 2001). The cutoff voltage was set at 10.2 volts. Curves were generated at various amperage loads. The graph is shown in Figure 11.

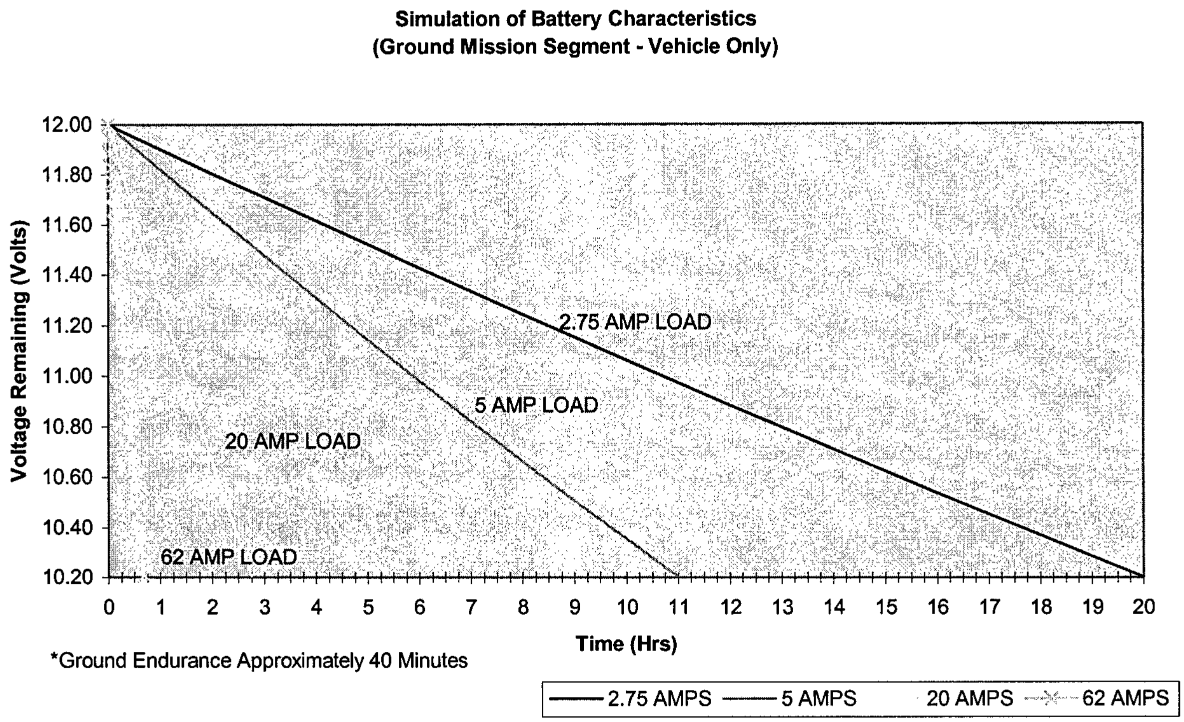


Figure 11 Ground Power Characteristics

The plot shows that the duration of the batteries at the 62 amp load is approximately 40 minutes. The CDD requires a 10-minute duration for the batteries. This exceeds the requirements of the CDD.

A plot was generated for the sensor loading on the remaining 12-volt battery. It is anticipated that most of the sensors will run continuously during the two-hour ground mission segment. The amperage load on the battery is approximately 12-amp. The endurance graph for the sensor battery is shown in Figure 12. The graph indicates that the endurance of the battery that powers the sensors is approximately 4.5 hours. This exceeds the requirements of the CDD.

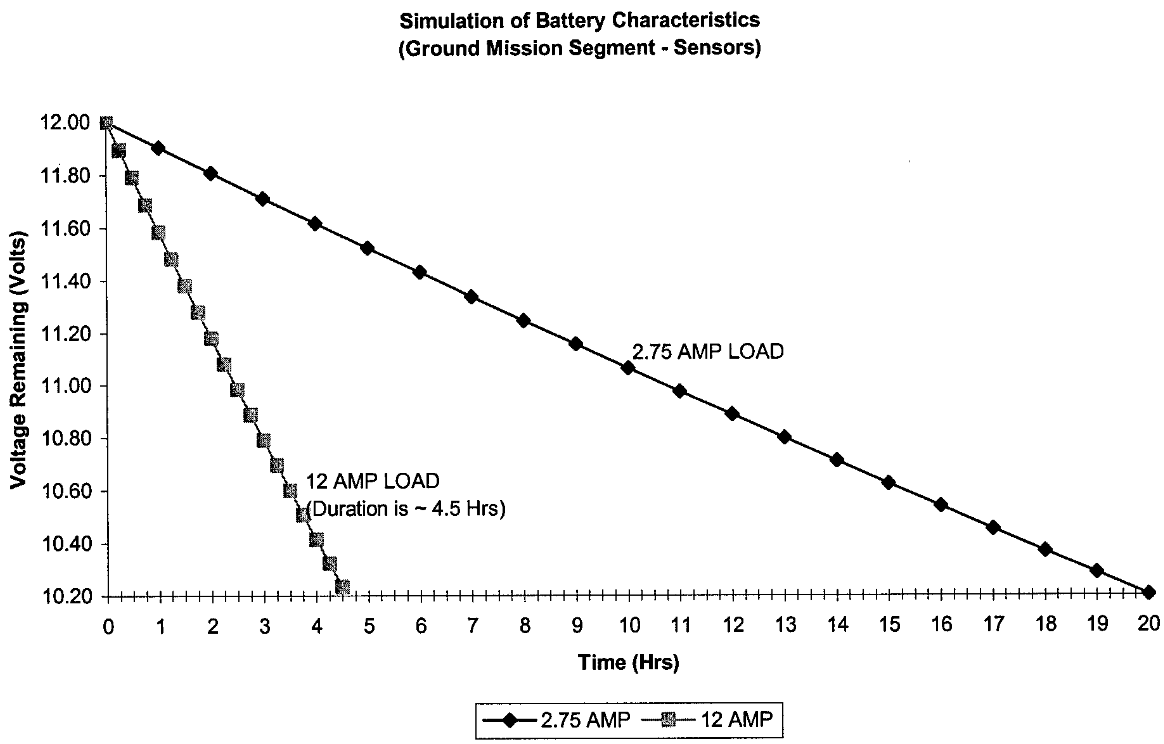


Figure 12 BatteryCharacteristics

2.9 Catia Layout

The main objective of this CAD study was to create a numerical assembly mock-up of the UHV. With this mock-up we could help each IPT member have a better understanding of the constraints linked with the required space, position of the payload, and combination of the various components: engine, rotor, ground vehicle, etc. The idea was to have a systematic approach (good knowledge of the goals but weak knowledge of the details rather than the contrary) due to the high interaction between the components. The goal was to match the CDD, the proposed concept, and the size of the HMMWV platform. Autocad 2D drawings were created including, one drawing for each of the intermediate concepts, these drawings represent a rough outline of the required shape. The three drawings were extrapolated from the artistic drawings shown during the intermediate review.

One concept was selected from the three concepts. It was necessary to generate a 3D layout in order to visualize how each component interacted. Catia was chosen because it can create a numerical assembly of volumetric and surface parts and consider components within a product. A fully reliable and modifiable model was developed by trial and error. The model was utilized to assess the weight and estimate the inertial data. The model can also be utilized for structural and aerodynamic assessments. A generative shape, a hulk, with the Autocad dimension and the artistic view were generated using Catia. Elements and components were added to the shell as they were identified. The drawings are shown in Figures 13 and 14.

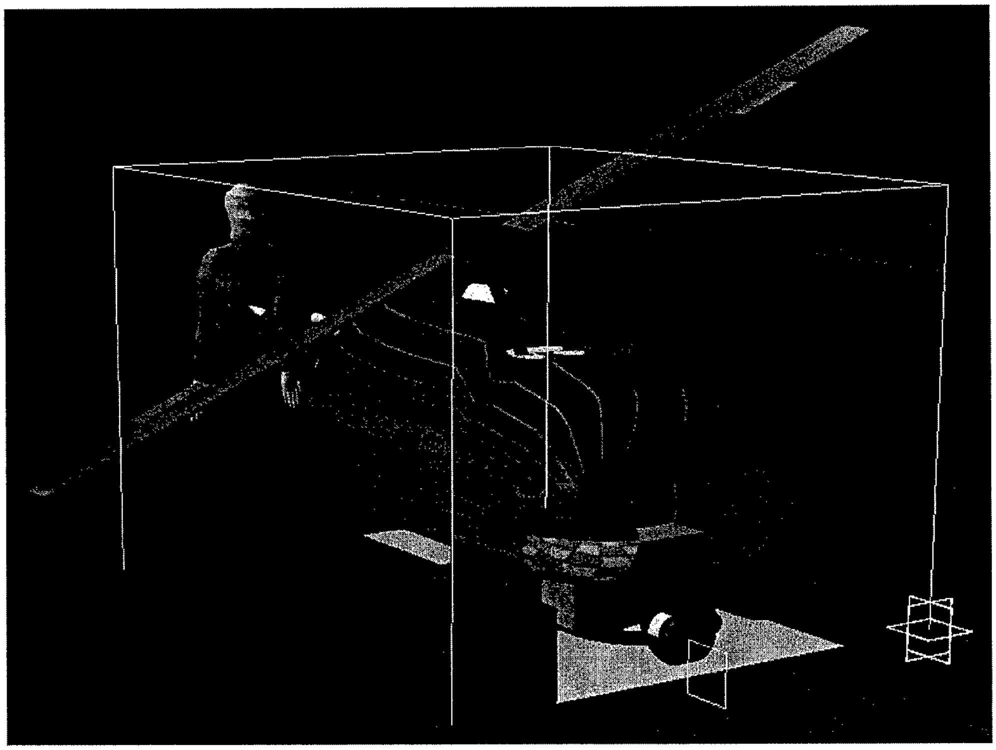


Figure 13 Catia Drawing 1

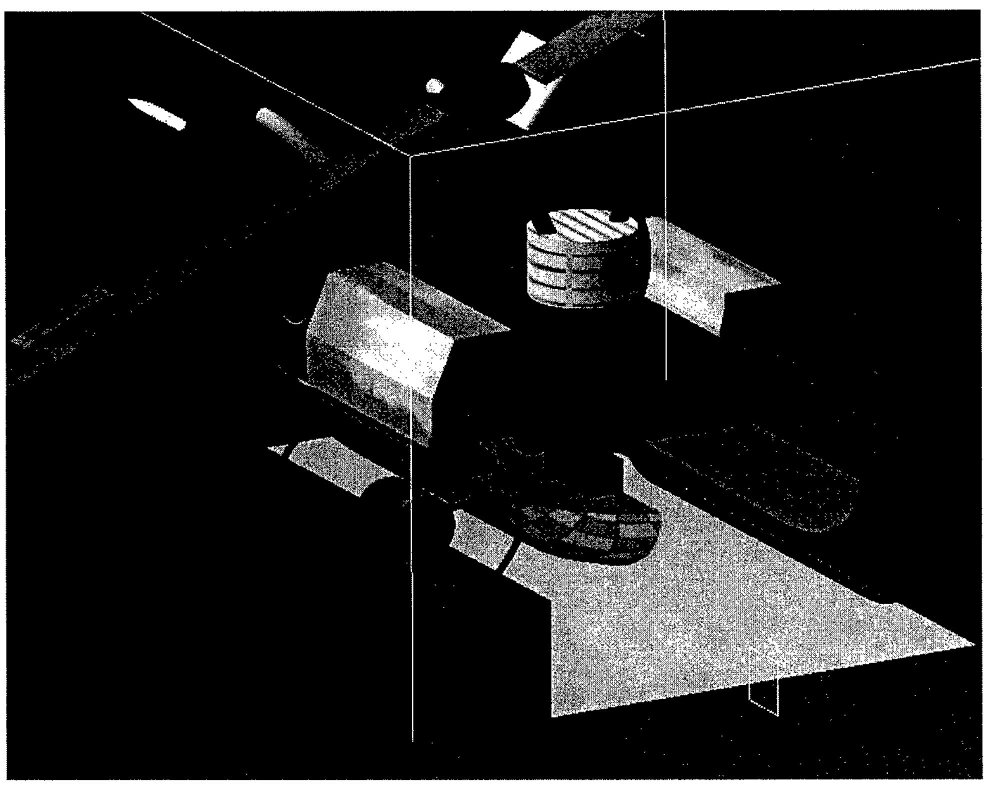


Figure 14 Catia Drawing 2

2.10 Technical Summary

The Mole is a two-piece design. The design utilizes a synchropter rotor system powered by a 150 hp Zoche diesel engine. The rotor disk radius is estimated at 7.2 ft. The helicopter carries an independently powered ground vehicle. The helicopter is fully capable of surveillance flights without the added weight of the ground vehicle. The weight of the air and ground vehicle with fuel is 1387 lbs including a 20% allowance for design contingency. The total weight with the support and handling equipment is 1487 lbs. This includes spare parts and needed ground equipment. The system is capable of 500 fpm VROC. The ground vehicle is powered by two electric motors. Docking of the ground vehicle can be achieved by two methods: 1) the ground vehicle can drive under the aircraft to redock; and 2) the aircraft can airlift the vehicle during the hover segment. With this two-piece design enhanced ground maneuvers are possible, and overall ground mission endurance is increased. For dangerous missions, the aircraft can return to the ground vehicle while the ground vehicle remains behind. This increases the overall survivability of the system. The disadvantages of this system include: 1) some duplication of sensors will be required; 2) the system will require a minimum of two brains; and 3) a transmission is required for the synchropter rotors, adding additional weight to the system.

Table 23 Concepts Technical Information

Comparison Criteria	Proposed Concept Name
Overall Specifications	
Air Configuration	Synchropter Rotor System
Ground Configuration	Three Wheels
Payload Mass, kg (lb)	Max. 60 lbs
Gross Takeoff Weight. kg (lb)	1387 lbs
Aero Propulsion Type	Zoche Diesel Engine
Energy Source for Air Transport	Disiel Grade #2 (10 Gals)
Ground Propulsion Type	DC Electric Motors
Energy Source for Ground Transport	3 – 12 V Batteries
Hovering Power, Kw (hp)	137 hp
Cruise Power, Kw, (hp)	40 hp
Basis of Semi-Autonomous Control	MIAG
Primary BLOS Method	CDL Class IV/V SATCOM
Primary Navigation Method	DGPS/Terrain Map
Primary Sensor Type	DVAL FLIR/CLD Cameras
Chemical/Biological Sensor	Air: Customer Specified Package Ground: Lab-On-A-Chip
Method of Sling Attachment	Four latch system on the Air Unit
Method of Deploying Payload at Range	Pulley and Latch system
Enabling Technology	Existing
Overall Dimensions, Stored	7.57' x 4.94' x 3.82'
Fuel Weight	79 lb

3.0 Implementation Issues

Programmatics is responsible for developing a project plan and acquisition strategy for the entire life cycle of the program. This consists of creating a Program Work Breakdown Structure (WBS), estimating a life cycle schedule from concept to disposal, and estimating cost for the entire life cycle. Uncertainty and risks must also be considered when developing the project plan, as these will affect scheduling and cost. An Integrated Program Management Array will need to be developed, listing the component elements of the WBS, along with associated costs, scheduling, risks, and resources (McInnis, 2002).

Constructing a schedule and cost estimate is typically viewed as a technical activity. However, developing a project plan for a complicated system is mostly an art, requiring lots of intuition, judgment, and guesswork. The project's success will be measured by how closely it meets the original project plan. Therefore, developing a realistic project plan, rather than bowing to pressure to create an unrealistic optimistic one is a crucial challenge (Little, 2001).

3.1 Programmatics Ground Rules and Assumptions

In the past, Unmanned Aerial Vehicles (UAV's) have been developed for Department of Defense (DoD) use through (1) contractor initiatives, (2) defense acquisition (milestone) programs, and (3) Advanced Concept Technology Demonstrations (ACTD's). Due to the Initial Operational Capability (IOC) being scheduled for 2012, it will be necessary to use an accelerated acquisition program. This will allow for shorter timelines and lessened oversight requirements. The acquisition program put in to effect will be based on the New DoD 5000 Model, but will not be subjected to all statutory (i.e., legislated) and regulatory (i.e., imposed by DoD) requirements (USD & ASD Staff).

Operating and Support (O&S) costs typically constitute a major portion of a system's life cycle costs and, therefore, are critical to the evaluation of acquisition alternatives (OSD). Using the army's current Tactical Unmanned Aerial Vehicle (TUAV) or Shadow 200 as an example for distribution, the Unmanned Hybrid Vehicle (UHV) will be used to provide close range (i.e. less than 50 km) reconnaissance, surveillance, and target acquisition to the ground maneuver brigade commander. One UHV "system" will consist of two ground control stations (GCS's), one portable ground control station, one portable ground data terminal, four remote video terminals (RVT's), and a minimum of three UHV's. To fully deploy one entire system will require at least four High Mobility Multipurpose Wheeled Vehicles (HMMWV's) and seventeen personnel. If maintenance is required, a fifth HMMWV and five additional personnel will be required. For full self-sustaining operational capability, it will be necessary to use at least three C-130's (TUAV, 2000).

Eventually, four systems will be delivered to each of the army's current ten divisions. Three will be deployed to the direct support (DS) companies and one to the general support (GS) companies of the Military Intelligence (MI) battalion. This will result in at least forty systems being deployed at peak operational capability (TUAV, 2000).

The customer has requested 300 total UHV's or units to be produced. Two additional units will be produced as prototypes. Approximately twenty-six percent of the 300 units will be classified as spares. The number of spares is based on historical attrition rates associated with past UAV programs (Carmichael. 1996). A portion of the spares may be stored in sealed containers for up to ten years and placed in strategic locations for use in rapid response situations (USD & ASD Staff, 2001).

3.2 Work Breakdown Structure

A Program WBS was developed using the Department of Defense Handbook Work Breakdown Structure (MIL-HDBK-881) as a guide. The primary challenge is to develop a Program WBS early in the conceptual stages of the program, which will evolve through iterative analysis as the program progresses. The success or failure of a project can be directly related to the development of the WBS (McInnis, 2002). The WBS provides a framework that assists during the life of the program in the following ways:

- Separates a defense material item into its component parts, making the relationships of the parts clear and the relationships of the tasks to be completed to each other and to the end product clear.
- Significantly affects planning and the assignment of management and technical responsibilities.
- Assists in tracking the status of engineering efforts, resource allocations, cost estimates, expenditures, high risk areas, and technical performance.

The Program WBS encompasses the entire program and consists of at least three levels. Level one is the entire defense material item (i.e., the UHV). Level two lists the major elements of the defense material item, and Level three lists the elements subordinate to Level two major elements. The WBS needs only to list the top three levels unless items of high risk or cost are identified. It is the Program Manager's (PM's) responsibility to maintain the Program WBS as it evolves and to develop a WBS Dictionary that lists and defines the WBS elements. By the end of the development phase, the Program WBS should be fully defined to its lowest level (DoD Staff, 1998).

The Program WBS is located in Appendix A. The Program WBS is shown as both an outline and a wire diagram. Note that each product element in the WBS will have an associated corresponding Integrated Product Team (IPT). The IPT encompasses each of the life cycle processes (i.e. development, manufacturing, testing / verification, deployment, operations, support, training, and disposal) (Gunther, 2002).

3.3 Life Cycle Schedule

The projected life cycle for this program began with concept exploration in Fiscal Year (FY) 2002 at the University of Alabama in Huntsville (UAH) and is projected to continue until disposal sometime in FY2030. This timeline was determined by establishing IOC to occur during FY2012, as stated in the Concept Description Document (CDD), and assuming a program life expectancy of approximately twenty years as is customary for Army programs (OSD). Figure 16 shows the O&S phase of a typical twenty-year life expectancy. The total number of units to be produced and fielded has been distributed over the twenty-year period from FY2010 to FY2030. This will allow for improvements to be made as new technology develops and problems with the final design become apparent after the first units have been deployed. This will also allow for the program to be cancelled ahead of the scheduled disposal date if problems with fielded units cannot be remedied.

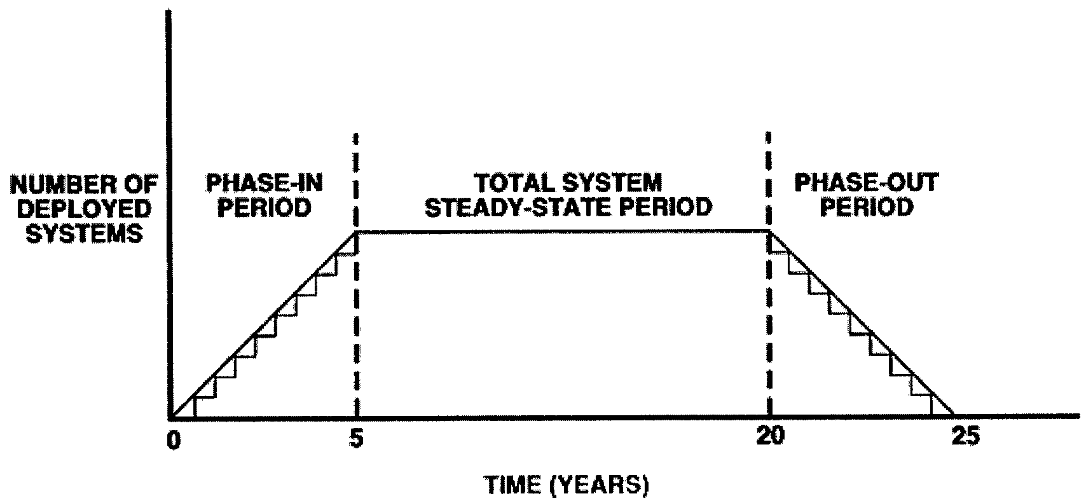


Figure 15 System Life Expectancy O&S Phases (OSD)

Phase 0 (concept exploration) began in FY2002 and will continue until the Milestone Decision Authority (MDA) has reviewed the project and determined that Milestone A (MS A) has been reached. This should occur in FY2003, and Phase I (concept and technical development) will begin. Phase I will continue until the MDA reviews the project and has determined that MS B has been reached. This should occur in FY2007 and Phase II (system development and demonstration) will begin at this time. Two prototype units will be produced in FY2008. The MDA will review the project and should allow the project to proceed to MS C sometime in FY2010, if the program is determined to be successful. At this time Phase III (production and deployment) will begin. Low-Rate Initial Production (LRIP) should also begin in FY2010, and should consist of a total of seventeen units being produced (i.e., UHV's for four systems and five spare units). The production phase will begin with the LRIP and continue until FY2025, with IOC being reached in FY2012. Unless a decision is made to cancel the program early or extend it past the program life expectancy, disposal will begin in FY2030 and continue through FY2035.

A list of all statutory and regulatory requirements that need to be considered during each phase, but not necessarily met before proceeding to the next phase, depending on the type of acquisition program will be put in effect (DoD Staff, 1998).

3.4 Life Cycle Costs

The total life cycle cost for one UHV or unit was estimated to be $7,200,000. (Note that all cost figures are for FY02, unless stated otherwise). This was determined using an informal rule based on historical experience. The production cost of a fixed wing aircraft is directly proportional to its empty weight (i.e., before mission equipment is added) (USD & ASD Staff, 2001). A figure of $1500 per pound (based on FY94 dollars) was adjusted for inflation for FY02 to be approximately $1800 per pound (Woodrow, 2002). Using the assumed desired weight of 1000 lbs. resulted in a production cost of $1,800,000 per unit. This cost was then multiplied by the 300 total units, requested by the customer, in order to determine the production cost for the entire program. This resulted in an estimated cost of $2,160,000,000 for the total life cycle of the program.

Table 24 lists the breakdown of total life cycle cost for the program. Also shown is the estimated total cost per unit. The total cost was broken down as follows. Ten percent of the total cost was assumed to be Research, Development, Test, and Evaluation (RDT&E), twenty-five percent was assumed for production, and sixty-five percent was assumed for O&S. Disposal cost typically represents a small fraction of the total life cycle cost and was therefore excluded (Gunther, 2002). Figure 17 illustrates the life cycle phases and how they relate to the total life cycle cost.

Table 24 Life Cycle Cost Per Unit

Costing Phase	**Percent of Total Cost**	**Total Program Cost ($) FY02**	**Unit Cost ($) FY02**
RDT&E	10	216,000,000	720,000
Production	25	540,000,000	1,800,000
O&S	65	1,404,000,000	4,680,000
Disposal	n/a	n/a	n/a
Total	100	2,160,000,000	7,200,000

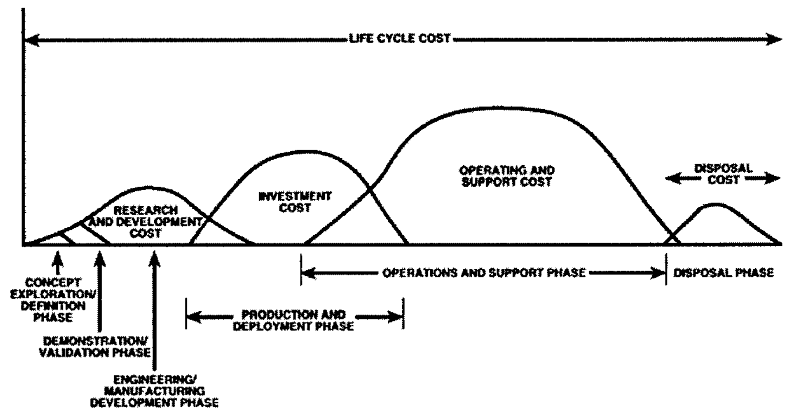


Figure 16 Program Life Cycle (OSD)

Using the tentative production and deployment schedule seen in Table 22, the minimum estimated amount of funding needed for the FY's shown was determined and can be seen in Table 23. Note that RDT&E and production costs only include the UHV's and not the extra equipment needed to field a fully operational system. All units will not be produced, nor will all systems be deployed in the FY's shown. Rather, they will be produced and distributed over several years. All of the funding necessary for production and deployment may be appropriated at one time in the FY's shown.

Table 25 Tentative Production and Deployment Schedule

FY for Production and Deployment to Begin	**Schedule Activity**	**UHV's Produced**	**UHV Spares Produced**	**Systems Deployed**
2008	Prototypes	2	0	1
2010	LRIP	12	5	4
2012	IOC	45	16	15
2015	Full Rate Production & Deployment	75	26	25
2020	Full Rate Production & Deployment	90	31	30
Total	---	224	78	75

Table 26 Summary of Funding Necessary to Fulfill Production & Deployment Schedule

	FY2008 ($)	FY2010 ($)	FY2012 ($)	FY2015 ($)	FY2020 ($)
UHV's	5,040,000	21,600,000	81,000,000	135,000,000	162,000,000
Spares	0	9,000,000	28,800,000	46,800,000	55,800,000
Systems	18,720,000	74,880,000	280,800,000	468,000,000	561,600,000
Total	23,760,000	105,480,000	390,600,000	649,800,000	779,400,000

The total estimated life cycle cost of the program (i.e., $2,160,000,000), when evenly distributed over thirty years, results in an annual budget of approximately $72,000,000. More funding per year may be needed during the first ten years of development and less per year during the disposal phase.

Total life cycle cost estimates will need to be reviewed and revised as necessary at each milestone decision review (OSD). Funding will come from the budget of the Department of the Army and can be divided among several budgetary items such as Research and Development (R&D), Tactical Unmanned Ground Vehicles, Tactical Unmanned Aerial Vehicles, etc. Other branches of the military may also fund R&D for new technology with cross-service applicability (USD & ASD Staff, 2001).

3.5 Risk Analysis

A historical basis was used to determine areas of risk that need to be considered. The Israeli military, prior to April 2001, conducted a study of its UAV mishaps after accumulating 80,000 hours of operations. (In comparison, the U.S. military had accumulated 50,000 hours of operations at that time.) Figure 18 shows the breakout of responsibilities for the mishaps. It was found that the propulsion, flight control system, and operator error accounted for 75 percent of all mishaps (USD & ASD Staff, 2001).

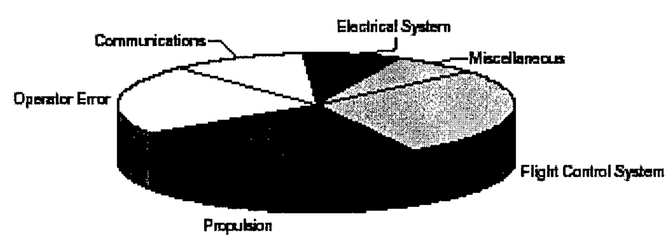


Figure 17 Israeli UAV Mishap Causes

Concentrating on these three areas early in the concept phase could significantly reduce the overall attrition rate and acquisition cost. Exploring new technologies and conducting tradeoff analysis for the propulsion, flight control system, and communications could reduce operation and support costs while increasing the reliability of the UHV. Designing the UHV to be fully autonomous could reduce operator error to near zero. This is due to the fact that software based performance is guaranteed to be repeatable, and software can be modified after an accident to remedy the situation causing the mishap. Again tradeoffs would have to be made, since current software technology needed to make the UHV fully autonomous may be too expensive to develop (USD & ASD Staff, 2001).

The potential savings from identifying and making improvements in the propulsion, flight control system, and operator error make a strong case for concentrating on these areas during the concept and development stages of the UHV.

3.6 Discussion of Application and Feasibility

The UHV design that is eventually produced and deployed will combine the capabilities currently performed separately by UAV's and Unmanned Ground Vehicles (UGV's). This will reduce O&S costs significantly, by reducing the number of personnel and the amount of training currently needed to field both UAV's and UGV's. The UHV will be have an advantage in certain mission areas commonly categorized as "the dull, the dirty, and the dangerous". That is, it will be able to monitor a much larger area than human sentries ("the dull") and thus become a force multiplier. It can be used to detect for nuclear, biological, or chemical (NBC) contamination without risk to human life ("the dirty"). The UHV will also be capable of assuming risky missions and can be used to prosecute heavily defended targets (currently left to forces on the ground or in the air) without loss of human life ("the dangerous"). In short, the opportunities available in effectively deploying the UHV are subject only to the imagination of the commanders (USD & OSD Staff, 2001).

The UHV will probably cost as much to develop as current manned air and ground vehicles. However, the cost of the UHV will be significantly cheaper over the entire life cycle. This is due to the fact that personnel can be sufficiently trained with simulators, unlike currently manned vehicles where some losses occur during training. There is no threat to the personnel if the UHV is lost during a mission. This will reduce the number of crews that have to be trained as replacements, thus saving time and money (USD & OSD Staff, 2001).

4.0 Company Capabilities

4.1 Company Overview

Hybrids R Us is comprised of a diverse group of engineers and managers. We draw on the skills of people versed in many different areas of specialization. With much enthusiasm and cooperation, Hybrids R Us strives to take on the challenges presented by our customers.

During the Baseline phase of this project, Hybrids R Us developed a solid plan for future development of the Rolling Feather. Additionally, Hybrids R Us developed strong relations with ESTACA. Using ESTACA as our primary propulsion contractor, we showed the capability of Hybrids R Us to work closely with the contractor while maintaining high quality and accuracy. This ability to manage an international project is very important in the development of the UHV.

Our ability to communicate the ideas necessary for the UHV project completion is evident in the technical presentations delivered by Hybrids R Us during the UHV project. If chosen, Hybrids R Us was prepared to present the baseline review to customer, mentors and review team. The entire UAH team and Arnauld Souchard of ESTACA delivered our alternate concepts presentation three times, in groups of three, which concluded Phase II. Following these presentations, the team demonstrated their ability to field and answer questions related to the alternate concepts presentations.

Hybrids R Us has demonstrated expertise in advanced technologies. With the instrumental advice of mentors from industry, Hybrids R Us was able to produce an extraordinary design of which we are extremely proud.

Our team includes experts in a variety of fields. If this proposal is ultimately accepted, Hybrids R Us will capably move forward with the UHV development. We propose the following distribution of team capabilities:

4.2 Personnel Description

- Mrs. Dana Quick - Hybrids R Us Project Manager and Programmatics Engineer
  Mrs. Quick has been a successful leader throughout all phases of the project. She brings organization and management skills necessary for the completion of this project. She is a necessity for the future of this project.

- Mr. Curt Kincaid - Hybrids R Us Systems Engineer and Mechanical Configuration/Structures Engineer
  Mr. Kincaid's perseverance and leadership has been instrumental during all phases of this project. He has completed his requirements in a timely manner and has taken on additional responsibilities. He is an asset to the team and will continue to benefit this design.

- Mrs. Amber Williams - Hybrids R Us Aerodynamics Engineer
  Mrs. Williams has worked diligently to find the best aerodynamic system possible. She is always willing to meet outside of regular appointed times and is always willing to help others. She is essential to the future development of the UHV.

- Mr. Paul Cheauvau - Hybrids R Us Propulsion and Power Team Engineer
  Mr. Cheauvau has worked diligently to create CAD drawings that can be used for this project. He has been very persistent and has worked very hard to overcome international barriers. His international communication skills will help the future endeavors of the UHV design.

- Mr. Matthieu Pamart - Hybrids R Us Propulsion and Power Team Engineer
  Mr. Pamart has been instrumental in the propulsion part of this project. His research and expertise allowed the team to develop a realistic and feasible project. His propulsion expertise is an asset that cannot be replaced.

- Mr. Arnauld Souchard de Lavoreille - Hybrids R Us Propulsion and Power Team Engineer
  Mr. Souchard's hard work and dedication to this project has helped make this project successful. His international experience proved to be essential, and his work on the propulsion team was fundamental. His endeavors into the propulsion portions of this project are essential for the further development of this project.

- Mr. Levi Gabre - Hybrids R Us Ground Robotics Engineer
  Mr. Gabre has played an instrumental role in all phases of this project. His positive attitude and friendly disposition along with his willingness to work hard have proven to be crucial for the success of Hybrids R Us. He will be instrumental in the completion of the ground robotics design.

- Ms. Tammy Jackson – Hybrids R Us Mission Simulation Engineer
  Ms. Jackson's dedication and willingness to work over and beyond her responsibilities is commendable. The design of The Mole could not have been completed had it not been for her hard work and commitment. Her dedication to this project will be an asset for the future of this project.

- Ms. April Burgess - Hybrids R Us Avionics/Sensors/Autonomous Flight Controls Engineer
  Ms. Burgess' friendly disposition was an asset to the entire team. She was always willing to work with others. Her charismatic attitude will be a necessity for the future development of the UHV.

- Mr. Joshua Freeman - Hybrids R Us Avionics/Sensors/Autonomous Flight Controls Engineer
  Mr. Freeman has proven to be an asset to Hybrids R Us. His experience in avionics and sensors has been a tremendous help to the project. His expertise is necessary for all future endeavors.

5.0 Summary and Conclusions

Hybrids R Us has developed The Mole as our solution to the UHV project. Our design is the perfect solution for the parameters defined in the CDD. The Mole uses existing technology that has previously been proven to be effective for use on helicopters, as well as technology that will be available in the next few years. With this mixture of technology, The Mole easily satisfies and exceeds all requirements. Using the technology selected for this design, the vehicle will be ready for deployment by the year 2012 and will continue to be the superior UHV for many years to come.

6.0 Recommendations

Recommendations include improvement of the speed requirement imposed on the ground operation described in the CDD. A two-hour ground operation seems unnecessary if the vehicle travels a distance of 0.5 km at a constant rate of 6 km/h. At this rate the ground vehicle would complete the mission in five minutes.

Another recommendation is that the series battery arrangement that was utilized in this design to power the electric motors be improved. It is recommended that conventional 12-volt or 24-volt motors be utilized. With 12-volt motors, 6-volt batteries can be used in a parallel/series combination. This will increase the amperage that is available and prolong the endurance of the batteries. The arrangement of the batteries should be more consistent with that utilized in electric golf cart designs.

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Appendix A - Concept Description Document

Appendix A - Concept Description Document

Concept Description Document Approval

The undersigned agree that the attached Concept Description Document as marked will be the basis the UAH IPT 2002 Design Competition. From this time forward, any questions or clarifications concerning the concept description document to the Customer shall be submitted in writing and the answer distributed to all UAH IPT's in writing.

To change the Concept Description Document Prior to April 30, 2002 shall require that the change be stated in writing and that a person authorized by every one of the signers below endorse the change with their signature. The revision will be labeled uniquely and distributed to all teams simultaneously.

The original of this document will be kept on file with the UAH Project Director. All signers will receive a copy of the original document.

James P. Winkeler, 2/5/02
James Winkeler, Customer

02/05/2002
Geof Morris, UAH IPT 01

Dana Quick, 02/05/02
Dana Quick, UAH IPT 02

Jennifer Pierce, 2/5/02
Jennifer Pierce, UAH IPT 03

Robert A. Frederick Jr, 2/5/02
Robert A. Frederick, Jr., UAH IPT 2002 Project Director

Appendix A - Concept Description Document

1. General Description of Operational Capability
1.1. Overall Mission Area
1.1.1. The system shall be a versatile scout and pack animal for future force structures, transporting critical payloads (e.g., ammunition, medical supplies).
1.1.2. The system shall be capable for use for target recognition and definition.
1.1.3. The system shall be capable for use in terrain definition.
1.1.4. The system shall be capable for use in situational awareness.
1.1.5. The system shall be capable of at least semi-autonomous operation, with full autonomous operation desirable.
1.1.5.1. The system shall be capable of human interface as required.
1.1.6. The system shall be capable of executing both a preplanned and diverted mission profiles.
1.1.7. The system shall be capable of navigating and functioning without a payload.
1.1.8. The system shall be capable of detecting chemical and biological threats.
1.1.9. The system shall be capable of detecting adverse weather conditions.
1.2. Operational Concept
1.2.1. The system shall be capable of nap of the earth flight (below the treeline).
1.2.2. The system shall be capable of operation at a range of 15-30 km ahead of the fighting force, with a 10% fuel reserve upon return.
1.2.2.1. The system shall be capable of gathering information on threat activities at range.
1.2.2.2. The system shall be capable of enhancing the RISTA/BDA.
1.2.2.3. The system shall be capable of transmitting information via secure data links and C2 structures BLOS.
1.2.2.4. The system shall be capable of using TF/TA/GPS/INS hardware and software to define and navigate complex terrain.
1.2.2.5. The system may encompass a degree of AI, ATR, and on-board decision making.
1.2.3. Payload Requirements
1.2.3.1. The system shall be capable of carrying a payload of 60lbs required gross weight, 120lbs desired gross weight, with a minimum payload volume of 2' x 2' x 2' [8 ft^3].
1.2.3.2. The system shall be capable of flying the payload to operational range in 30 minutes or less and be able to return from range in 30 minutes or less.
1.2.3.2.1. The vehicle will have a minimum cruise airspeed of 30 km/hr and a desired airspeed of 100 km/hr.
1.2.3.3 There shall be no power or data interfaces between the vehicle and the payload.
1.2.4. Mission Requirements
1.2.4.1. The system shall be capable of landing in an unprepared area with a ground slope of 12° maximum up or down.
1.2.4.1.1. The vehicle must have vertical takeoff and landing capabilities.
1.2.4.2. The system shall maximize survivability.

1.2.4.2.1. The system shall have a near quiet acoustic signature.
1.2.4.2.2. The system shall be designed for an operational altitude of 0 – 250 ft AGL required, 0-500 ft AGL desired.
1.2.4.2.3. The system shall be capable of a 200 fpm VROC [required], 500 fpm [desired], at 4000 ft and 95 °F, with the payload in place.
1.2.4.3. The system shall be designed to be transported via a HMMWV and trailer, and/or via external sling load by a UH-60 helicopter.

2. System Capabilities
   2.1. The system shall be capable of operation at an altitude of 4000ft, 95 degrees Fahrenheit ambient temperature, and not using more than 90% maximum rated power.
   2.2. Operational Performance
   2.2.1. The system shall possess essential performance, maintenance, and physical characteristics required to operate under adverse environmental conditions worldwide, down to –40 °F.
   2.2.2 The system shall possess essential performance, maintenance, and physical characteristics required to operate under adverse geographical conditions worldwide.
   2.2.3. The system shall be capable of operating from any unimproved land facility surface day or night, including low illumination.
   2.2.4. The system shall be capable of operation under and detection of battlefield obscurants.
   2.2.5. The system shall be capable of ground operations on unimproved roads at ground speeds of 6 km/hr [required], 12 km/hr [desired] for no less than two (2) hours at a radius of 0.5 km [required], 1 km [desired]. Unimproved roads: Non-prepared surfaces, not to have more than RMS of 1", which means, over 1 ft can not rise or dip more than one inch, no linear features, which means no barriers, blocks, bricks, big rocks, etc., nothing in path of vehicle except trail or road and finally, no more grade than 12 degrees.
   2.2.6. The system [vehicle and ground station] shall weigh no more than 1500 lbs [required], 1000 lbs [desired].
   2.2.7. The system shall use readily available diesel or jet fuel.
   2.3. The system shall possess the following electronic capabilities:
   2.3.1. Mission Planning System
   2.3.1.1. The system shall possess a point-and-click pre-mission planning system to simulate mission flight.
   2.3.1.2. The system shall possess data loading capabilities.
   2.3.1.3. The system shall be capable of coordination and reaction to immediate operational mission changes.
   2.3.1.4. The system shall be capable of processing self awareness and threat sensor inputs.
   2.3.1.5. The system shall be capable of enabling TF/TA from digital mapping information from satellite or other sources.
   2.3.2. Avionics

2.3.2.1. Communications and navigation suite architecture shall be compatible with emerging military data links.

2.3.3. Communications

2.3.3.1. System communications shall be robust and have clear secure modes of operation

2.3.3.2. Communications shall be simultaneously LOS and BLOS which can include satellite relay or other relay system compatibility.

2.3.3.3. System must posses IFF and be compliant to all FCC/military communication regulations.

2.3.3.4. System must be capable of communication with and sharing digital mapping/targeting information with other DoD RISTA platforms.

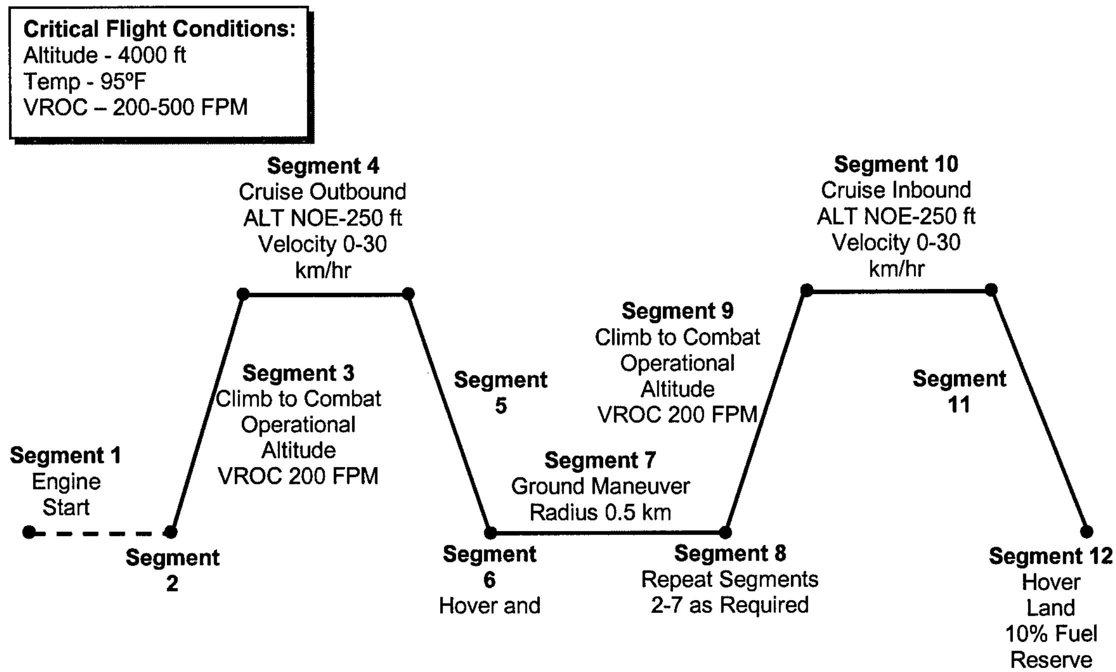
2.3.4. Connectivity

2.3.4.1. The system shall be interoperable with other DoD systems envisioned for the 2012 battlefield to the maximum extent possible and be compatible with service unique command, control, and information systems.

3.0 ACRONYM LIST

AGL	Above Ground Level
AI	Artificial Intelligence
ATR	Automatic Target Recognition
BDA	Battlefield Damage Assessment
BLOS	Beyond Line of Sight
C2	Command and Control
DoD	Department of Defense
FCC	Federal Communications Commission
fpm	feet per minute
ft	feet
GPS	Global Positioning System
HMMWV	High-Mobility, Multipurpose Wheeled Vehicle
IFF	Identify Friend or Foe
INS	Inertial Navigation System
IPT	Integrated Product Team
km	kilometers
km/hr	kilometers per hour
lbs	pounds
LOS	Line Of Sight
RISTA	Reconnaissance, Intelligence, Surveillance, Target Acquisition
RMS	Root Mean Square
TA	Terrain Avoidance
TF	Terrain Following
UAH	The University of Alabama in Huntsville
UH-60	Utility Helicopter
VROC	Vertical Rate Of Climb

Baseline Mission Profile



Appendix B - White Paper

Competition Sensitive Document Attached

Team 2

The Attached Document is Competition Sensitive until May 1,2002.

If you find this document and do not know what to do with it,

put it in a secure place and notify

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Alternate Concepts White Paper

IPT 2

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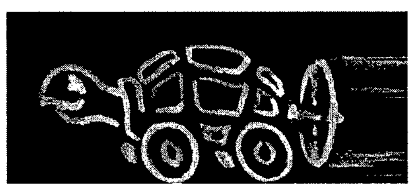

March 5, 2002

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Abstract

In today's world, more than ever, there is a rise in the need for Unmanned Hybrid Vehicles (UHV). This is a vehicle that will combine air and ground capabilities into one common unit. Motivations for such a vehicle include: Reconnaissance, Chemical/Biological Detection, Delivery of Critical Cargo, Target Recognition and Designation, Terrain Definition, Situational Awareness, and Communication/Data Relay. Hybrids R US has developed four concepts for such a vehicle. The 1st concept, The Rolling Feather, is a four wheeled, co-axial rotor design. The 2nd concept is a two-piece design that achieves increased survivability in separation. The design allows surveillance and observation without the added weight of the ground vehicle compartment. The 3rd concept is a one-piece concept that achieves increased survivability through redundancy via four inducted fans. The last concept, the rotopter design attempts to combine the rotary advantages in aerodynamics with the flapping lift of a wing. The design selected for refinement in phase three, based on the evaluation matrices, is the two-piece concept.

Resumé

En monde de today.s, plus que jamais, il y a une élévation du besoin de véhicules hybrides non-pilotés (UHV). C'est un véhicule qui combinera des capacités d'air et de la terre dans un véhicule commun. Les motivations pour un tel véhicule incluent: Reconnaissance, détection de Chemical/Biological, la livraison de la cargaison critique, l'identification et la désignation de cible, la définition de terrain, la conscience situationnelle, et le relais de Communication/Data. Les Hybrides R USA a développé quatre concepts pour un tel véhicule. Le 1er concept, la plume de roulement, est des quatre roulés, conception coaxiale de rotor. Le 2ème concept est une conception en deux pièces qui réalise le survivability accru dans la séparation. La conception permet la surveillance et l'observation sans poids ajouté du compartiment moulu de vagabond. Le 3ème concept est un concept d'une seule pièce qui réalise le survivability accru par la redondance par l'intermédiaire de quatre ventilateurs installés. Le dernier concept, la conception de Rotopter, tentatives de combiner les avantages rotatoires en aérodynamique avec l'ascenseur s'agitant d'une aile. La conception choisie pour l'amélioration dans la phase trois, basé sur les matrices d'évaluation, est le concept en deux pieces.

Technical Description

1.0 Overview of Phase 2

The Unmanned Hybrid Vehicle (UHV) sought by the U.S. Advanced Systems Directorate is envisioned to provide essential scouting and target recognition to the Brigade Commander. The customer and all participating teams endorsed a Concept Description Document (CDD) finalizing the customer requirements for this system on February 5, 2002. Phase 1 of the project produced one baseline concept that attempted to satisfy the project (CDD) using existing technology. HYBRIDS R US at the University of Alabama in Huntsville has focused on synthesizing three alternative concepts. This White Paper provides a summary of the Baseline and our three alternative concepts. The key attributes of each concept are compared against the CDD. One of the concepts is selected for development in Phase 3.

1.1 Specification Summary

There are many important specifications set forth by the customer. The following is a list of some of the most important.

- Required airspeed of 30 km/h and desired of 100 km/h
- Required vertical rate of climb of 250 fpm and desired of 500 fpm
- Required ground speed of 6 km/h and desired of 12 km/h
- Flight Profile of Hover at Full Flight
- Required operational altitude of 0-250 ft AGL with desired of 0-500 ft
- The required endurance is 4 h with desired of 6 h
- Required payload of 60 lbs and desired of 120 lbs
- Required range of 15 km and desired of 30 km
- Required ground radius of 0.5 km and desired of 1 km
- Required operation capabilities of semi-autonomous and desired of autonomous
- Required transportable via HMMWV Trailer or UH-60 sling
- Required maximum weight of under 1500 lbs and desired of under 1000 lbs

Throughout the design process Hybrids R US will attempt to fulfill these requirements.

1.2 Key Challenges

The main challenge for this project is designing a very complex system such as the UHV in the time frame proposed. There are many areas of helicopter and ground vehicle design that have to be thoroughly examined and researched. Also, another challenge is using the technology today to produce a product that will be deployed in 2012. Advancements in technology occur on a daily basis, thus designing a system that will meet warfare needs ten years from now presents a difficult and complicated task. In addition, bringing together a diverse group of people to work toward developing a quality product that meets the customer's specifications requires an enormous amount of dedication and commitment. Other challenges include weight and size limitations on the design. The UHV must weight less than 1500 lbs and be transportable via a HMMWV trailer.

2.0 Description of Concepts

The concept designs for this project were developed to address the key challenges involved in meeting the requirements of the Concept Description Document. The challenges include: 1) weight restrictions; 2) size limitations; 3) 500 VROC desired; and 4) NOE flight conditions. The design iterations were based on the worse-case scenario in order to allow room for concept optimization in Phase 3 of the project. The Mole design is a two-piece design that achieves increased survivability in separation. The design allows surveillance and observation without the added weight of the ground vehicle compartment. The La Fouine is a one-piece concept that achieves increased survivability through redundancy via four inducted fans. The Hummingbird is a new rotor design that attempts to combine the rotary advantages in aerodynamics with the flapping lift of a wing.

2.1 Baseline Concept "Rolling Feather"

The Rolling Feather shown in Figure 1 utilizes a coaxial rotor system powered by a 125 hp IO-240 engine. The design is capable of 500 fpm VROC, and utilizes AV fuel. The power to hover at 4000 ft and 95°F is 87 hp and the cruising power is 53 hp. The radius of the rotor disk is estimated at 7.2 ft, with a disk loading of 9.21 lb_f/ft^2. The ground mission segment is accommodated by four wheel electric motors powered by six, six-Volt batteries. The system is capable of carrying a 60 lb payload with a weight estimated at 1500 lbs. The primary BLOS method is ground radio communication and the navigation method utilized is GPS. The primary sensor enabling the Rolling Feather to relay information is FLIR Camera. The advantages of this concept included: 1) compact rotor design; 2) no tail rotor is required. The disadvantages include: 1) weight; 2) engine uses AV fuel; 3) system is not semi-autonomous and 4) limited ground maneuvers.

2.2 Concept 2A "The Mole"

The Mole shown in Figure 2 is a two-piece design. The design utilizes Kaman intermeshing rotors powered by a 230 hp SMA SR/305 diesel engine. The rotor disk radius is estimated at six ft. The helicopter carries an independently powered ground vehicle. The helicopter is fully capable of surveillance flights without the added weight of the ground vehicle. This enhances the point-to-point flight endurance of the aircraft. The total system weight is estimated at 1472 lbs including a 35% allowance for design contingency. The system is capable of 500 fpm VROC. The ground vehicle is powered by two electric motors. Docking of the ground vehicle can be achieved by two methods: 1) the ground vehicle can drive under the aircraft to redock; and 2) the aircraft can airlift the vehicle during the hover segment. With this two-piece design enhanced ground maneuvers are possible. Overall ground mission endurance is increased. For very dangerous missions, the aircraft can return to the ground station while the ground vehicle remains behind. This increases the overall survivability of the system. The disadvantages of this system include: 1) some duplication of sensors will be required; 2) the system will require a minimum of two brains; and 3) a transmission is required for intermeshing rotors adding weight to the system.

2.3 Concept 2B "The Hummingbird"

The Hummingbird shown in Figure 3 utilizes a rotopter rotor design powered by a 180 hp Noelle turbine engine. The rotopter is a new innovative concept in rotor designs proposed by Dr. Vladimir Savov. A conventional helicopter needs a tail rotor to stop the craft from spinning in the opposite direction to the rotor blades. In the rotopter, the engine drives the crank causing the blades to go up and down. With careful selection of the airfoil angle, the blades will rotate as a result. With this system there is no moment transmitted to the rotopter blades, so there is no torque reaction. This eliminates the need for a tail rotor and conserves fuel. The Hummingbird design has a tandem rotor system with a disk radius of five ft. The advantages of this system include: 1) no torque reaction; 2) induced power losses are lower due to unsteady flow; and 3) the centrifugal force reduces compressive stress on the upper surface of the blade. Unfortunately, the system has only been used on very lightweight aircraft and the dual "flapping" motion of the rotors require large power inputs. Use of flapping rotors could also be detrimental to ground maneuverability. Folding the rotors may present a problem, so two five ft radius rotors may not be feasible for ground operation. The energy source used for ground transport includes both batteries and fuel cells. The current information on fuel cells is limited and it appears that they may produce a weight problem. At the present, the rotopter is considerably less efficient than a conventional rotor design. Furthermore it is questionable whether or not technology will be advanced enough to deploy this concept in 2012. .

2.4 Concept 2C "La Fouine"

The La Fouine design is shown in Figure 4. The concept utilizes a tilt rotor system powered by a Saphir 180 hp Turbine Engine. This concept design addresses the major flaw that all helicopters possess. As the horizontal speed of a helicopter increases, its rotors move more quickly through the air as they circle toward the front of the aircraft and less quickly through air as they circle to the rear. This causes the helicopter to become unstable at high speeds. The tilt-rotor aircraft addresses this flaw because the rotors can tilt forward during flight and become like propellers on an airplane. This allows a tilt rotor to achieve airplane type speeds and remain stable. The rotor disk on the La Fouine design has a radius of four ft. The design achieves redundancy via four inducted fans. This increases the overall survivability of the system. The tilt rotor performs a conversion of VTOL aircraft into a more ordinary aircraft by tilting the propeller from vertical to horizontal to achieve horizontal flight. The ground segment is powered by two electric motors requiring 36 Volts and 62 Amps. The total system weight is estimated at 1487 lbs including a 20% allowance for unidentified components. The design is capable of 500 fpm VROC. Ground endurance is estimated at two hours. The disadvantages of this system include: 1) high dust is anticipated due to the turbine engine; 2) increased noise level; and 3) a complex mechanical system must be evaluated to optimize the rotor diameter.

3.0 Selection of Final Concept

An Evaluation Matrix was generated in order to objectively compare the merits of the each concept. The completed matrix is included in Table-1. Each concept was compared against the baseline concept, "The Rolling Feather." A plus "+" was assigned to indicate that the concept is better than the baseline with regards to the respective attribute. Likewise a minus "-" indicates that the concept is inferior to the baseline with regards to the respective attribute. " " indicates that the concept is the same as the baseline with regards to the respective attribute. A scoring system was implemented in order to tally the total score of each concept when compared against the baseline. For each plus, the concept scored one point. For each minus, the concept scored negative one point. For each blank, the concept scored zero points. The Evaluation Matrix revealed that the "Mole" was the highest-ranking concept, with a total score of six. The "La Fouine" was chosen as the second-best concept, with a total score of four. It proved superior to the baseline with respect to air speed, vertical climb, horsepower required for flight profile, and range. The "La Fouine" was better than the baseline except for the attribute of weight. The "Mole" was superior to the baseline with regards to air speed, vertical climb, horsepower required for flight profile, and overall endurance. The "Mole" was inferior to the baseline based on the complexity issues introduced in the two-piece design. Complexity is encountered in duplication of sensors and software, as well as, in the docking mechanism that will have to be designed in order to reattach the ground vehicle. The design team feels that the added complexity is handsomely offset by the increased capability of the system. A two-piece design offers more flexibility in mission profile. The "Mole" can be used for surveillance and biological/chemical detection without the added weight of the ground vehicle. This reduces of the weight in flight by approximately 251 lbs, and increases the point-to-point flight endurance of the aircraft. The "Mole" also allows enhanced ground operations because clearance of the rotors is not an issue. The ground vehicle, being much lighter than the overall system, will have enhanced ground endurance as well as increased maneuverability. For these reasons combined, the team recommends that the "Mole" be selected as the concept to refine in Phase 3 of this project.

4.0 Phase 3 Plan

4.1 Key Issues to Address

The key issues and problems for Phase3 are as follows:

- The rotor disk diameters require optimization for weight reasons and right of claim.
- The biological/chemical detection sensor is a vague area at this time. Hybrids R Us has currently been unable to find the necessary technical data.
- The overall system weight needs to be addressed.
- Optimal diesel engine has yet to be determined.
- The method of making the vehicle TF/TA needs attention.
- The BLOS communication requires more attention and detail.
- The energy source for the power of the ground vehicle needs further investigation. The option of fuel cells is under debate at this time, but not enough technical data has been acquired to make a decision yet.

4.2 Phase 3 Schedule

The concepts shown in the white paper were all evaluated at the most extreme flight conditions and as described in the CDD. These conditions are flight at 4000 ft and 95°F. The concepts were also analyzed to perform at the desired specifications level. Now that the concept is selected further more detailed analysis will be performed on it. This analysis will allow the system to be fine-tuned to achieve the best performance possible. Aerodynamic analysis will determine the ideal design so that the system can achieve the best performance with the least amount of necessary power. A more thorough weight breakdown will determine where the system can be made lighter. The general design presented here will be expanded on to give specific detail about the selected system.

5.0 Illustrations

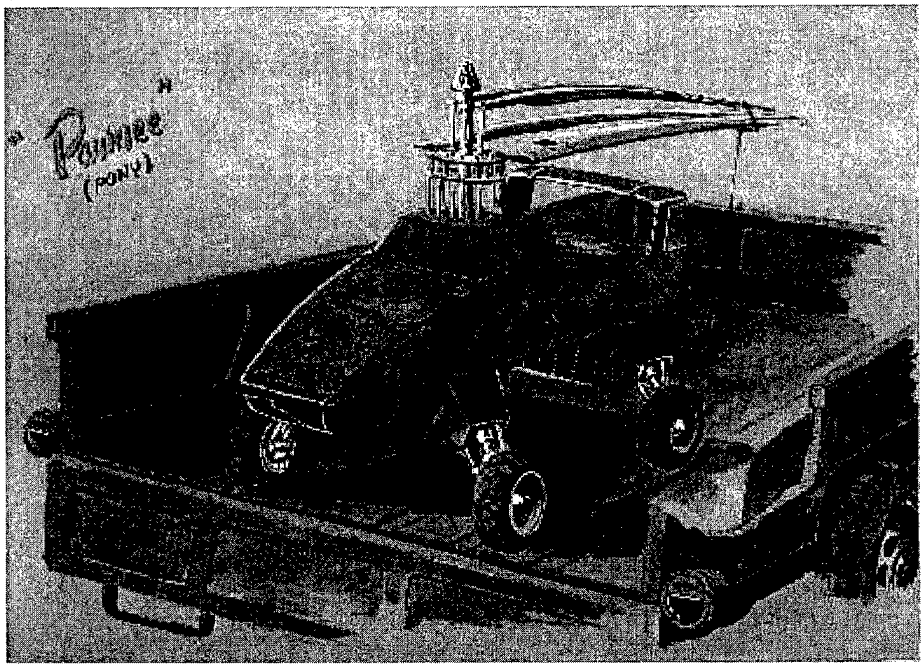

Figure 1. Baseline "Rolling Feather"

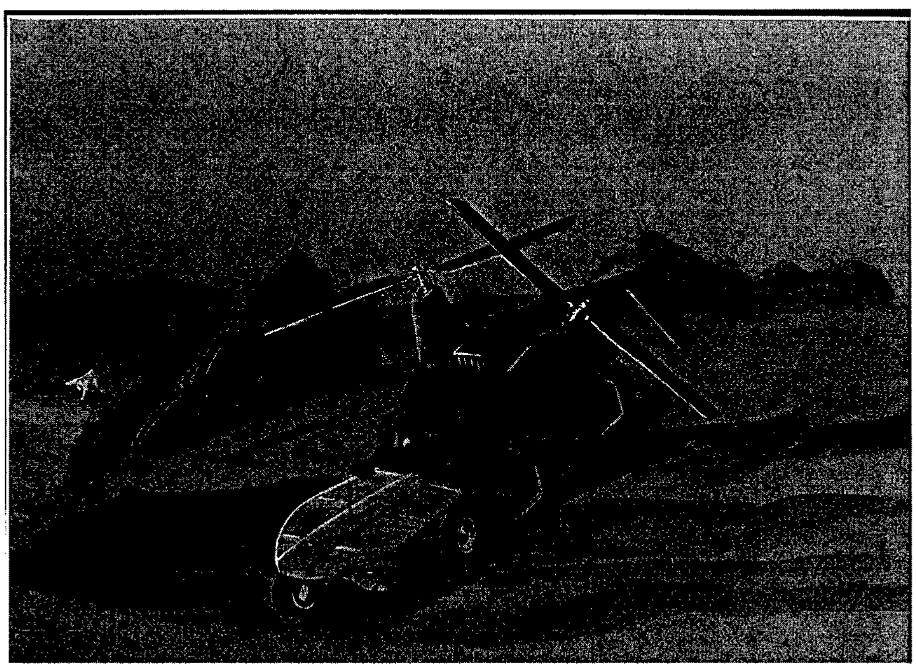

Figure 2. Concept 2A "The Mole"

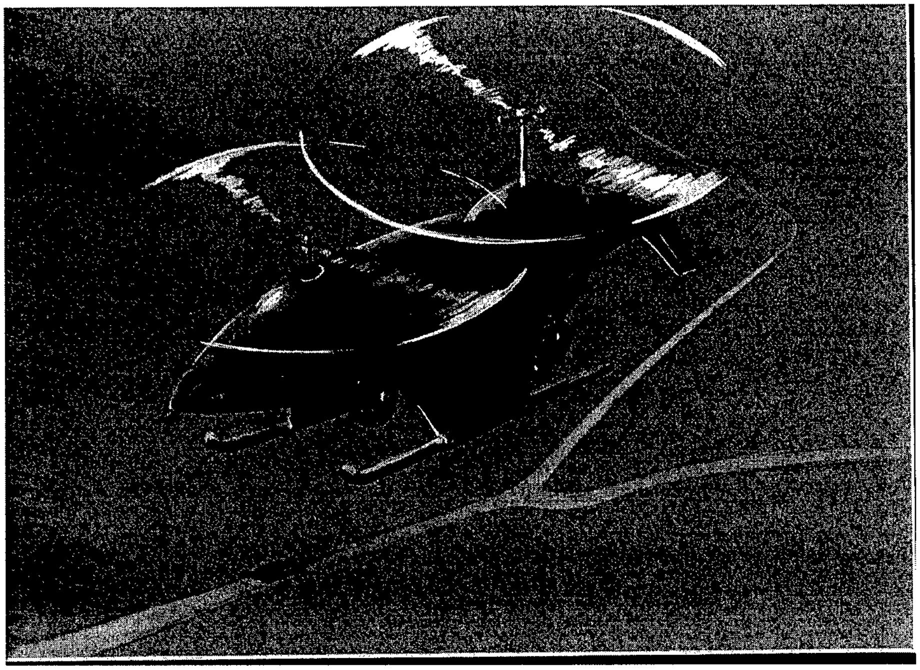

Figure 3. Concept 2B "The Hummingbird"

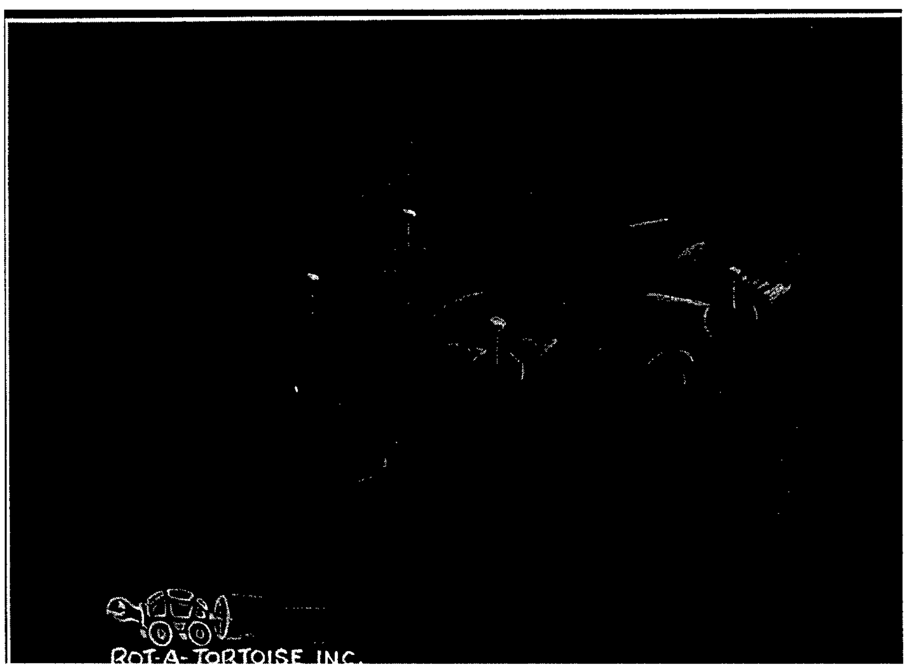

Figure 4. Concept 2C "La Fouine"

Table 1. Concept Evaluation Matrix

	Factor	Baseline	2-A	2-B	2-C
Required Attributes		**Rolling Feather**	**The Mole**	**The Hum-ming-bird**	**La Fouine**
Airspeed, 30 km/hr	1		+	NA	+
Vertical Climb, 200 fpm	1		+	–	+
Ground Speed, 6 km/hr	1				
Flight Profile, Hover-Full	1		+	–	+
Operational Altitude, 0-250 ft AGL	1			NA	
Endurance, 4 hours	1		+		+
Payload, 60 lbs	1				
Range, 15 km	1		+		+
Operation, Semi-Autonomous	1		–		
Transportable, HMMWV, UH-60	1				
Max Weight, 1500 lbs	1		+	+	–
Team-Selected Decision Attributes					
Existing Technology	1			–	
Ground Maneuverability	1		+		
TOTALS		***0***	***6***	***-2***	***4***

Table 2. Concepts Comparison

Common Engineering Criteria	Baseline Rolling Feather	2A The Mole	2B The Hummingbird	2C La Fouine
Air Configuration	Coaxial Rotor	Intermeshing Rotor	Flapping Rotor	Tilt Rotor
Ground Configuration	Wheels-rubber Golf Cart type	3-Wheeler Independent Ground System	Tracks	3-Wheeler
Payload Mass, lb	60 lb	60 lb	60 lb	60 lb
Assumed Gross Takeoff Weight. Lb	1109lb	1472 lb	1372 lb	1622 lb
Aero Propulsion Type	Piston Engine	V-4 Turbo-Diesel Engine	Micro turbo Noelle 180 Engine	Saphir 100 Turbine Engine
Disk Loading lbf/ft^2	9.21	5.65	9.55	4.77
Energy Source for Air Transport	AvGas 100 LL	Number 2 Diesel Fuel	AV Fuel	AV Fuel
Ground Propulsion Type	Electric Motors	Electric Motor	Electric Motors	Electric Motor
Energy Source for Ground Transport	Electric (Battery)	DC Batteries	DC Batteries & Fuel Cells	DC Batteries
Power to HOGE at 4k ft. - 95° F, hp	87 hp	125 hp	NA	120 hp
Cruise Power, hp	53 hp	103 hp	NA	109 hp
Basis of Autonomous control	none	Flight Management System	Flight Management System	Flight Manage-ment System
Primary BLOS Method	Ground radio	SATCOM relay	SATCOM relay	SATCOM relay
Primary Navigation Method	GPS	GPS/Terrain Map	GPS/Terrain Map	GPS/Terrain Map
Primary Sensor Type	FLIR Camera	FLIR Camera	FLIR Camera	FLIR Camera
Enabling Technology	Existing	Existing	Non-Existing	Existing

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Word List

AGL	Above Ground Level
AI	Artificial Intelligence
ATR	Automatic Target Recognition
BDA	Battlefield Damage Assessment
BLOS	Beyond Line of Sight
C2	Command and Control
CDD	Concept Description Document
DoD	Department of Defense
FCC	Federal Communications Commission
fpm	feet per minute
ft	feet
GPS	Global Positioning System
HMMWV	High-Mobility, Multipurpose Wheeled Vehicle
IFF	Identify Friend or Foe
INS	Inertial Navigation System
IPT	Integrated Product Team
km	kilometers
km/hr	kilometers per hour
lbs	pounds
LOS	Line Of Sight
RISTA	Reconnaissance, Intelligence, Surveillance, Target Acquisition
RMS	Root Mean Square
TA	Terrain Avoidance
TF	Terrain Following
UAH	The University of Alabama in Huntsville
UH-60	Utility Helicopter
VROC	Vertical Rate Of Climb

Appendix C – Sample Calculations

C1 – Aerodynamics

Trade Study Results

Coaxial

Area (ft^2)	R/C (ft/sec)	Density (lb-sec^2/ft^4)	Aspect Ratio	Thrust (lb)	blades	Cdo
113.10	5.000	2.11E-03	10	750	2	0.01
chord (in)	**FM**	**Gap**	**Distance between rotors (ft)**	**K factor**	**Cl**	**Cd**
7.20	0.75	0.15	0.9	1.15	1.56	1.23
Solidity	**Ct**	**Disk Loading (lb/ft^2)**	**Lift Slope Factor**	**Blade Pitch (rad)**	**Inflow Factor**	
6.37E-02	0.012	13.26	5.7	0.21	0.08	

Thrust (lb)	Induced Power (HP)	Profile Power (HP)	Total Power (HP)	Rotor Tip Velocity (ft/sec)	Rotor Frequency (rpm)
750.00	183.80	9.19	192.99	510.47	812.44

Synchropter

Radius (ft)	Rotor Area (ft^2)	Area (ft^2)	Density	blades	AR
6	113.10	169.65	2.11E-03	2	10.00
solidity	**Cl**	**CT**	**RC (ft/sec)**	**chord (in)**	**Downwash (ft/s)**
0.06	1.557	0.012	5.00	7.20	45.763

Cdo	Cd	Disk Loading (lb/ft^2)	Lift Slope Factor	Blade Pitch (rad)	Inflow Factor
0.001	1.23	8.84	5.70	0.21	0.08

Weight (lb)	Blade Loading (lbf/ft^2)	Tip Loss Factor	Hover k factor	Blade Area (ft^2)	Blade Volume (in^3)
1500	208.333	0.980	1.33	7.2	1791.59
Stagger Distance (ft)	**Overlap Area (ft^2)**	**Thrust (lb)**	**Blade Thickness (in)**	**Blade Weight (lb)**	
3	28.274	750	0.86	115.20	
Figure of Merit	**Flat Plate Area (ft^2)**	**Cp**			
0.75	0.17	1.07E-03			

Weight (lb)	Thrust (lb)	Induced Power (HP)	Profile Power (HP)	Total Power (HP)	Rotor Tip Velocity (ft/sec)	Rotor Frequency (rpm)
1500	750.00	175.77	0.93	176.70	512.12	815.06

Sample Equations (Equations were taken from Seddon, Newman, 2001)

$A_R = \pi * R^2$ Rotor Area

$A_o = \pi * s^2$ Overlap Area

$A_t = (A_R - A_0) * 2$ Total Blade Area

$AR = \frac{R}{c}$ Aspect Ratio

$\sigma = \frac{b * c}{\pi * R}$ Solidity

$v_i = \sqrt{\frac{W}{2 * \rho * A_t}}$ Downwash Velocity

$L_d = \frac{W}{A_t}$ Disk Loading

$i = \frac{\sigma * a}{16} * \sqrt{1 + \left(\frac{32}{\sigma * a}\right) * p} - 1$ Inflow Factor

$C_T = 0.25 * \sigma * a * (p - i)$ Coefficient of Thrust

$C_D = \frac{4}{(-1.8)^2}$ Coefficient of Drag (Taken from Seddon, Newman, 2001)

$A_b = R * c * b$ Blade Area

$V_b = R * c * t * 4$ Blade Volume

$L_b = \frac{W}{A_b}$ Blade Loading

$$W_b = \rho_b * A_b$$ Blade Weight

$$k = 1.46 - \left(0.253 * \left(\frac{s}{R}\right)\right)$$ Hover Power Factor

$$P_i = \frac{\left(k * \left(0.5 * RC + \sqrt{(0.5 * RC)^2 + \frac{W}{2 * \rho * A^t}}\right) * W\right)}{550}$$ Induced Power

$$V_t = \sqrt{\frac{\frac{W}{2}}{\rho * A_r * C_T}}$$ Rotor Tip Velocity

$$P_o = \frac{\frac{1}{8} * C_{do} * \rho * \sigma * A_r * 2 * V_t^3}{550}$$ Profile Power

$$P_t = P_i + P_o$$ Total Power

$$f_r = \frac{\frac{V_t}{R} * 60}{2 * \pi}$$ Rotor Frequency

Radius (ft)	Rotor Area (ft^2)	Area (ft^2)	Density	blades	AR
7.2	162.86	269.17	2.11E-03	2	10.29
solidity	**Cl**	**CT**	**RC (ft/sec)**	**chord (in)**	**Downwash (ft/s)**
0.06	1.557	0.012	8.33	8.40	35.099

Cdo	Cd	Disk Loading (lb/ft^2)	Lift Slope Factor	Blade Pitch (rad)	Inflow Factor
0.001	1.23	5.20	5.70	0.21	0.08

Weight (lb)	Blade Loading (lbf/ft^2)	Tip Loss Factor	Hover k factor	Blade Area (ft^2)	Blade Volume (in^3)
1400	138.889	0.980	1.35	10.08	2926.26
Stagger Distance (ft)	**Overlap Area (ft^2)**	**Thrust (lb)**	**Blade Thickness (in)**	**Blade Weight (lb)**	
3	28.274	700	1.01	148.07	
Figure of Merit	**Flat Plate Area (ft^2)**	**Cp**			
0.7	0.27	1.04E-03			

Weight (lb)	Thrust (lb)	Induced Power (HP)	Profile Power (HP)	Total Power (HP)	Rotor Tip Velocity (ft/sec)	Rotor Frequency (rpm)
1400	700.00	136.24	0.70	136.94	416.82	552.82

CARBON FABRICS
CONSTRUCTION DATA CHART

Style	Finish	Weave	Industry Description	Yarn Description: Warp	Yarn Description: Fill	Fiber Producer	Count Ends X Picks	Weight Ounces/Sq. Yd.	Image
94100	Greige	5 HS	6K-135-5H	6K-T300	6K-T300	Amoco	12 X 12	10.9	
94101*	Greige	Plain	3K-70-P	3K-T300	3K-T300	Amoco	12 X 12	5.7	
94105	Greige	5 HS	3K-280-5H	3K-T300	3K-T300	Amoco	18 X 18	8.3	
94106	Greige	4 HS	3K-70-4HS	3K-T300	3K-T300	Amoco	12 X 12	5.5	
94107	Greige	8 HS	3K-135-8H	3K-T300	3K-T300	Amoco	24 X 23	10.9	IMAGE
94200	Greige	5 HS	6K-135-5H	6K-AS4	6K-AS4	Hexcel	11 X 11	10.9	
94205	Greige	5 HS	3K-280-5H	3K-AS4	3K-AS4	Hexcel	17 X 17	8.3	
94206	Greige	4 HS	3K-70-4HS	3K-AS4	3K-AS4	Hexcel	11 X 11	5.5	IMAGE
94207	Greige	8 HS	3K-135-8H	3K-AS4	3K-AS4	Hexcel	22 X 22	10.9	
94209	Greige	Plain	3K-70-P	3K-AS4	3K-AS4	Hexcel	11 X 11	5.7	
94231	Greige	Plain	3K-70-P	3K-AS4C	3K-AS4C	Hexcel	13 X 13	5.9	
94232	Greige	4 HS	3K-4HS	3K-AS4C	3K-AS4C	Hexcel	13 X 13	5.9	
94233	Greige	2x2 Twill	3K-TW	3K-AS4C	3K-AS4C	Hexcel	13 X 13	5.9	IMAGE
94400	Greige	5 HS	6K-135-5H	6K-G30-500	6K-G30-500	Toho	12 X 12	10.9	

*** 94101 (3K70P) in 10, 25, 50 and 100 Yd. rolls are available for shipping from NFGS**

94401	Greige	Plain	3K-70-P	3K-G30-500	3K-G30-500	Toho	12 X 12	5.7	
94405	Greige	5 HS	3K-280-5H	3K-G30-500	3K-G30-500	Toho	17 X 17	8.3	IMAGE
94407	Greige	8 HS	3K-135-8H	3K-G30-500	3K-G30-500	Toho	24 X 23	10.9	
94901	Greige	Plain	3K-70-P	3K	3K	Various	12 X 12	5.7	IMAGE
94932	Greige	4 HS	3K-4HS	3K	3K	Various	13 X 13	5.9	
94933	Greige	2x2 Twill	3K-TW	3K	3K	Various	13 X 13	6.2	

4.2.1.1 MatWeb.com, The Online Materials Database

4.2.1.2 Titanium Carbide, TiC

Subcategory: Carbide; Ceramic

Physical Properties	Metric	English	Comments
Density	4.94 g/cc	0.178 lb/in³	theoretical
Mechanical Properties			
Knoop Microhardness	2000 - 2750	2000 - 2750	50 g load, single crystal
Knoop Microhardness	2000 - 2400	2000 - 2400	100 g load, single crystal
Knoop Microhardness	1800 - 5900	1800 - 5900	
Hardness, Rockwell A	93	93	
Tensile Strength, Ultimate	258 MPa	37400 psi	114 at 980°C; 59 at 1200°C
Modulus of Elasticity	448 - 451 GPa	65000 - 65400 ksi	
Vickers Microhardness	3200	3200	100 g load
Poisson's Ratio	0.18 - 0.19	0.18 - 0.19	at RT
Shear Modulus	110 - 193 GPa	16000 - 28000 ksi	
Shear Modulus	186 GPa	27000 ksi	single crystal
Shear Strength	757 - 2958 MPa	110000 - 429000 psi	227 MPa at 1600°C; 89 MPa at 1925°C
Electrical Properties			
Electrical Resistivity	0.00018 - 0.00025 ohm-cm	0.00018 - 0.00025 ohm-cm	
Thermal Properties			
CTE, linear 20°C	7.7 µm/m-°C	4.28 µin/in-°F	
Melting Point	3065 °C	5550 °F	
Solidus	3050 °C	5520 °F	
Liquidus	3080 °C	5580 °F	
Descriptive Properties			

Crystal Structure	Cubic	NaCl Structure

References are available for this material.

4.2.1.3 MatWeb.com, The Online Materials Database

4.2.1.4 Overview - Ethylene Vinyl Acetate; Molded/Extruded

4.2.1.5

4.2.1.6 Subcategory: Ethylene Vinyl Acetate; Polymer; Thermoplastic

4.2.1.7 Close Analogs: Click the button to view the proprietary polymer grades listed in MatWeb that belong to this class. Please be aware that some proprietary polymers may not be listed because they fall into more than one class or because of ambiguity in manufacturer's information.

4.2.1.8 Top of Form

4.2.1.9 Proprietary Grades

4.2.1.10 Bottom of Form

4.2.1.11 Key Words: EVA; Plastics, Polymers

4.2.1.12 The data below has been taken from proprietary materials in the MatWeb database. Each property value reported is the average of appropriate MatWeb entries and the comments report the maximum, minimum, and number of data points used to calculate the value. The values are not necessarily typical of any specific grade, especially less common values and those that can be most affected by additives or processing methods.

Physical Properties	**Metric**	**English**	**Comments**
Density	0.925 - 0.956 g/cc	0.0334 - 0.0345 lb/in³	Average = 0.939 g/cc; Grade Count = 23
Apparent Bulk Density	0.545 - 0.577 g/cc	0.0197 - 0.0208 lb/in³	Average = 0.57 g/cc; Grade Count=5
Water Absorption	0.1 %	0.1 %	Grade

			Count = 1
Environmental Stress Crack Resistance	1 - 1000 hour	1 - 1000 hour	Average = 500 hr; Grade Count = 8
Linear Mold Shrinkage	0.01 cm/cm	0.01 in/in	Grade Count = 1
Melt Flow	1.5 - 800 g/10 min	1.5 - 800 g/10 min	Average = 120 g/10 min; Grade Count = 20
Mechanical Properties			
Hardness, Shore A	58 - 76	58 - 76	Average = 70.5; Grade Count = 4
Hardness, Shore D	15 - 33	15 - 33	Average = 26.1; Grade Count = 7
Tensile Strength, Ultimate	1.9 - 21 MPa	276 - 3050 psi	Average = 9.4 MPa; Grade Count = 12
Tensile Strength, Yield	2.5 - 20 MPa	363 - 2900 psi	Average = 7.9 MPa; Grade Count = 14
Elongation @ break	50 - 1300 %	50 - 1300 %	Average = 470%; Grade Count = 21
Tensile Modulus	0.04 - 0.14 GPa	5.8 - 20.3 ksi	Average = 0.079 GPa; Grade Count = 10
Flexural Modulus	0.009 - 0.14 GPa	1.31 - 20.3 ksi	Average = 0.062 GPa; Grade Count = 9
Secant Modulus	0.056 GPa	8.12 ksi	Grade Count = 1
Izod Impact, Notched	NB	NB	Grade

			Count = 1
Tensile Impact Strength	2.5 - 805 kJ/m²	1.19 - 383 ft-lb/in²	Average = 460 kJ/m²; Grade Count = 6
Dart Drop	49 g	0.108 lb	Grade Count=1
Electrical Properties			
Electrical Resistivity	1E+15 ohm-cm	1E+15 ohm-cm	Grade Count = 4
Dielectric Constant	2.5 - 3	2.5 - 3	Average = 2.7; Grade Count = 3
Dielectric Constant, Low Frequency	2.5 - 3	2.5 - 3	Average = 2.7; Grade Count = 3
Dielectric Strength	27.5 kV/mm	699 kV/in	Grade Count = 1
Dissipation Factor	0.013 - 0.1	0.013 - 0.1	Average = 0.046; Grade Count = 3
Dissipation Factor, Low Frequency	0.013 - 0.1	0.013 - 0.1	Average = 0.046; Grade Count = 3
Comparative Tracking Index	600 V	600 V	Grade Count=3
Thermal Properties			
CTE, linear 20°C	30 - 160 µm/m-°C	16.7 - 88.9 µin/in-°F	Average = 120 µm/m-°C; Grade Count=3
Heat Capacity	2.2 J/g-°C	0.526 BTU/lb-°F	Grade Count = 1
Melting Point	61 - 105 °C	142 - 221 °F	Average = 84.1°C; Grade Count = 22

Deflection Temperature at 0.46 MPa	37 °C	98.6 °F	Grade Count=2
Deflection Temperature at 1.8 MPa	23 °C	73.4 °F	Grade Count=2
Vicat Softening Point	23 - 105 °C	73.4 - 221 °F	Average = 69.4°C; Grade Count = 15
Brittleness Temperature	-69 °C	-92.2 °F	Grade Count=1
Flammability, UL94	HB	HB	Grade Count = 3
Oxygen Index	19 %	19 %	Grade Count = 1
Optical Properties			
Haze	5.1 %	5.1 %	Grade Count = 1
Gloss	80 %	80 %	Grade Count = 1
Transmission, Visible	80 %	80 %	Grade Count = 6
Processing Properties			
Processing Temperature	180 °C	356 °F	Grade Count = 1

4.2.1.13

4.2.1.14

4.2.1.15 MatWeb.com, The Online Materials Database

4.2.1.16 Beralcast® 363 Beryllium-Aluminum Alloy

Subcategory: Beryllium Alloy; Metal; Metal Matrix Composite; Nonferrous Metal

Key Words: Starmet Corporation

Component	Wt. %

Material Notes:
Aluminum content above calculated as remainder.

Beralcast® 363 is used primarily for precision cast, high strength structural applications.

General Beralcast® information: High damping. Lighter than aluminum and titanium. Higher ductility than pure beryllium. Several times stiffer than either aluminum, magnesium, or aluminum-based metal matrix composites. Can be cast into complex shapes. The microstructure consists of a primary beryllium phase in a continuous aluminum matrix. Beralcast finds uses in satellite components, avionics packaging, aircraft/missile systems, wrought products, computers, motion control, and golf clubs.

Information provided by Starmet Corporation.

Modulus of Elasticity	202 GPa	29300 ksi	in tension
Compressive Yield Strength	226.1 MPa	32800 psi	Yield
Bearing Yield Strength	476.4 MPa	69100 psi	Pin Type (e/D = 2.0)
Poisson's Ratio	0.2	0.2	
Fatigue Strength	117.2 MPa	17000 psi	Axial (R=-1.0); 1E+7 Cycles
Shear Strength	247.5 MPa	35900 psi	Pin Double Shear Strength

Electrical Properties

Electrical Resistivity	0.0000043 ohm-cm	0.0000043 ohm-cm	

Thermal Properties

CTE, linear 20°C	13.7 µm/m-°C	7.61 µin/in-°F	at 25°C
Heat Capacity	1.25 J/g-°C	0.299 BTU/lb-°F	
Thermal Conductivity	105.5 W/m-K	732 BTU-in/hr-ft²-°F	
Melting Point	Max 645 °C	Max 1190 °F	Liquidus
Liquidus	645 °C	1190 °F	

4.2.1.17 MatWeb.com, The Online Materials Database

4.2.1.18 KEP Kepital® Grade FG2025 25% Glass Fiber Reinforced Acetal Copolymer

Subcategory: Acetal; Polymer; Thermoplastic

Key Words: Polyacetal; Polyoxymethylene; Korea Engineering Plastics; Polymer Technology & Services, LLC (PTS)

Material Notes:
Information provided by US distributor Polymer Technology and Services, LLC (PTS).

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Physical Properties	Metric	English	Comments
Density	1.59 g/cc	0.0574 lb/in³	
Water Absorption	0.2 %	0.2 %	24 hours at 73°C
Mechanical Properties			
Hardness, Rockwell M	95	95	
Tensile Strength, Yield	136.8 MPa	19800 psi	at 1/8 in (3.2 mm).
Elongation @ break	3 %	3 %	at 1/8 in (3.2 mm).
Flexural Modulus	9.03 GPa	1310 ksi	at 1/8 in (3.2 mm).
Flexural Yield Strength	205.2 MPa	29800 psi	at 1/8 in (3.2 mm).
Izod Impact, Notched	0.96 J/cm	1.8 ft-lb/in	at 3.2 mm (1/8 in).
Thermal Properties			
Melting Point	203 °C	397 °F	
Maximum Service Temperature, Air	163 °C	325 °F	Deflection Temp
Deflection Temperature at 0.46 MPa	164 °C	327 °F	
Deflection Temperature at 1.8 MPa	163 °C	325 °F	
Flammability, UL94	HB	HB	at 1/16 in (1.6 mm)

Appendix C 3 – Mission Simulation

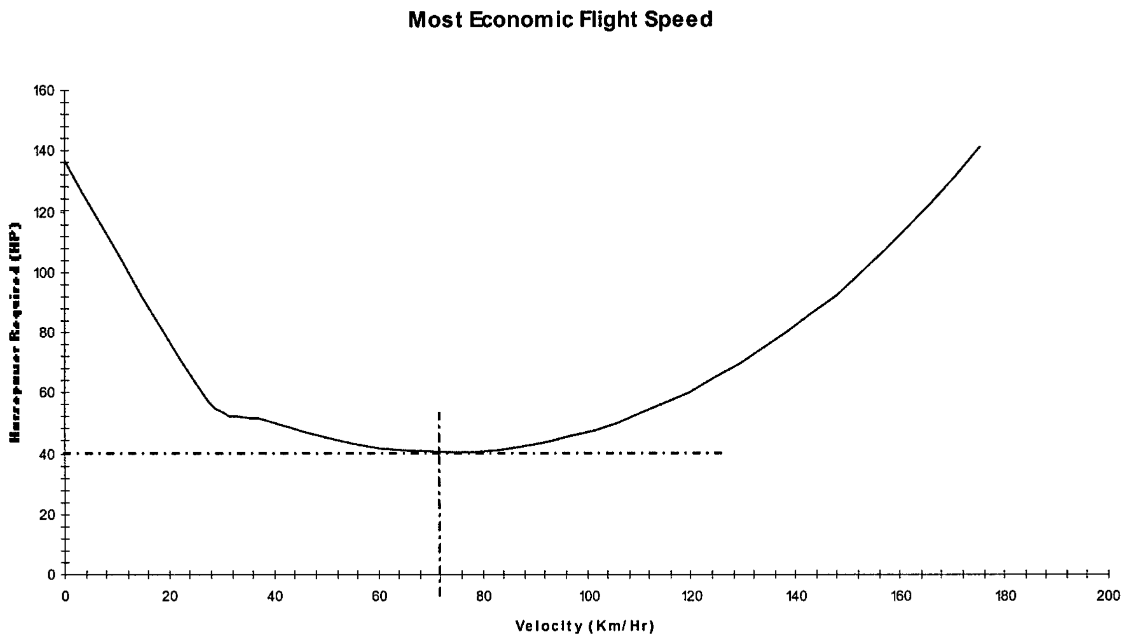


Figure E4-1: Most Economical Flight Speed

MISSION SIMULATION - The Mole

DIESEL FUEL #2 **(lb/gallon)** 7.9

MISSION PROFILE

VROC 500 ft/min
Start Elev. 4000 ft
Alt 250 ft

SEGMENT #	DESCRIPTION	TIME (hr)	DISTANCE (km)	AIRSPEED (km/hr)	Ratio of Power Required	FCR (gallons/hr)	(gallons)	(lb)	FCR (lb/hr)
1	WARM UP/IDLE	0.08			0.65	4.8	0.40	3.2	38.1
2	HOVER	0.02			0.91	6.7	0.11	0.9	53.3
3	CLIMB	0.01			0.95	7.1	0.06	0.5	55.7
4	CRUISE	0.42	30	72.00	0.27	2.0	0.83	6.5	15.6
5	DESCENT	0.05			0.45	3.3	0.17	1.3	26.4
6	HOVER/LAND	0.08			0.91	6.7	0.56	4.4	53.3
7	GROUND (ELECTRICAL)	2.00	0.5						
8	WARM UP/IDLE	0.08			0.65	4.8	0.40	3.2	38.1
9	HOVER	0.02			0.91	6.7	0.11	0.9	53.3
10	CLIMB	0.01			0.95	7.1	0.06	0.5	55.7
11	CRUISE	0.42	30	72.00	0.27	2.0	0.83	6.5	15.6
12	DESCENT	0.05			0.45	3.3	0.17	1.3	26.4
13	HOVER/LAND	0.08			0.91	6.7	0.56	4.4	53.3
						TOTAL FUEL USED	**4.3**	**gallons**	

TOTAL FORWARD DISTANCE (Km)	60
TOTAL TIME (hr)	3.32

WEIGHT OF FUEL USED	**34**	**lbs**
With NOE FLIGHT	**6.0**	**gallons**
(2X Forward Flight)	**47**	**lbs**
With 10% FULE RESERVE	**6.5**	**gallons**
With 10% FULE RESERVE	**51.4**	**lbs**

NOTE: Actual Fuel tank was sized for a 10 gallon capacity. Total Weight of fuel is 79 lbs.

Actual Fuel Reserve is 67%

Table C3-1: Breakout of Mission Profile Simulation

Flight Endurance with the Ground Vehicle (Point to Point) - 10 gallon fuel tank

	MISSION SIMULATION - The Mole					VROC	500	ft/min	
			DIESEL FUEL #2			Start Elev.	4000	ft	
MISSION PROFILE			**(lb/gallon)**	7.9		Alt	250		ft
SEGMENT #	DESCRIPTION	TIME (hr)	DISTANCE (km)	AIRSPEED (km/hr)	Ratio of Power Required	FCR (gallons/hr)	(gallons)	Fuel Weight (lb)	FCR (lb/hr)
1	WARM UP/IDLE	0.08			0.65	4.8	0.40	3.2	38.1
2	HOVER	0.02			0.91	6.7	0.11	0.9	53.3
3	CLIMB	0.01			0.95	7.1	0.06	0.5	55.7
4	CRUISE	4.72	**340**	72.00	0.27	2.0	**9.35**	73.9	15.6
		4.83				TOTAL FUEL	9.9		

Table C3-1: Flight Endurance Point-to-Point

Flight Endurance without the Ground Vehicle (Point to Point) - 10 gallon fuel tank

MISSION SIMULATION - The Mole

DIESEL FUEL #2 (lb/gallon) 7.9

VROC 500 ft/min
Start Elev. 4000 ft
Alt 250 ft

MISSION PROFILE

SEGMENT #	DESCRIPTION	TIME (hr)	DISTANCE (km)	AIRSPEED (km/hr)	Ratio of Power Required	FCR (gallons/hr)	(gallons)	Fuel Weight (lb)	FCR (lb/hr)
1	WARM UP/IDLE	0.08			0.65	4.8	0.40	3.2	38.1
2	HOVER	0.02			0.73	5.4	0.09	0.7	42.9
3	CLIMB	0.01			0.95	7.1	0.06	0.5	55.7
4	CRUISE	5.90	425	72.00	0.21	1.6	9.35	73.9	12.5
		6.01				TOTAL FUEL	9.9		

Table C3-2: Flight Endurance Point-to-Point without Ground Vehicle

Estimate of Re-Docking Duration (10 gallons of fuel)

MISSION SIMULATION - The Mole

DIESEL FUEL #2 (lb/gallon) 7.9

VROC 500 ft/min
Start Elev. 4000 ft
Alt 250 ft

MISSION PROFILE

SEGMENT #	DESCRIPTION	TIME (hr)	DISTANCE (km)	AIRSPEED (km/hr)	Ratio of Power Required	FCR (gallons/hr)	(gallons)	Fuel Weight (lb)	FCR (lb/hr)
1	WARM UP/IDLE	0.08			0.65	4.8	0.40	3.2	38.1
2	HOVER	0.02			0.73	5.4	0.09	0.7	42.9
3	CLIMB	0.01			0.95	7.1	0.06	0.5	55.7
4	CRUISE	0.42	30	72.00	0.21	1.6	0.66	5.2	12.5
5	DESCENT	0.05			0.45	3.3	0.17	1.3	26.4
6	RE-DOCK (Hover)	**0.90**			0.91	6.7	6.07	48.0	53.3
7	CLIMB	0.01			0.95	7.1	0.06	0.5	55.7
8	CRUISE	0.42	30	72.00	0.27	2.0	0.83	6.5	15.6
9	DESCENT	0.05			0.45	3.3	0.17	1.3	26.4
10	HOVER/LAND	0.08			0.91	6.7	0.56	4.4	53.3
				TOTAL GALLONS USED (10% FUEL RESERVE)			9.97		

*** Docking time available 50 minutes**

NOTE: This does not include NOE Flight Conditions.
This does not take into consideration the fact that the craft is getting lighter due to fuel consumption.

Table C3-3: Estimate of Redocking Duration

Estimate of Re-Docking Duration with NOE Flight Conditions (10 gallons of fuel)

MISSION SIMULATION - The Mole VROC 500 ft/min

DIESEL FUEL #2 Start Elev. 4000 ft

MISSION PROFILE **(lb/gallon)** 7.9 Alt 250 ft

SEGMENT #	DESCRIPTION	TIME (hr)	DISTANCE (km)	AIRSPEED (km/hr)	Ratio of Power Required	FCR (gallons/hr)	(gallons)	Fuel Weight (lb)	FCR (lb/hr)
1	WARM UP/IDLE	0.08			0.65	4.8	0.40	3.2	38.1
2	HOVER	0.02			0.73	5.4	0.09	0.7	42.9
3	CLIMB	0.01			0.95	7.1	0.06	0.5	55.7
4	CRUISE	0.42	30	72.00	0.21	1.6	0.66	5.2	12.5
5	DESCENT	0.05			0.45	3.3	0.17	1.3	26.4
6	RE-DOCK (Hover)	**0.68**			0.91	6.7	4.61	36.4	53.3
7	CLIMB	0.01			0.95	7.1	0.06	0.5	55.7
8	CRUISE	0.42	30	72.00	0.27	2.0	0.83	6.5	15.6
9	DESCENT	0.05			0.45	3.3	0.17	1.3	26.4
10	HOVER/LAND	0.08			0.91	6.7	0.56	4.4	53.3
		TOTAL GALLONS USED (10% FUEL RESERVE)					10.00		

*** Docking time available 40 minutes**

NOTE:This does not take into consideration the fact that the craft is getting lighter due to fuel consumption.

Table C3-4: Redocking Estimate with NOE Flight Conditions

Estimate of Re-Docking Duration without refueling

MISSION SIMULATION - The Mole VROC 500 ft/min

DIESEL FUEL #2 Start Elev. 4000 ft

MISSION PROFILE **(lb/gallon)** 7.9 Alt 250 ft

SEGMENT #	DESCRIPTION	TIME (hr)	DISTANCE (km)	AIRSPEED (km/hr)	Ratio of Power Required	FCR (gallons/hr)	(gallons)	Fuel Weight (lb)	FCR (lb/hr)
1	WARM UP/IDLE	0.08			0.65	4.8	0.40	3.2	38.1
2	HOVER	0.02			0.91	6.8	0.11	0.9	53.4
3	CLIMB	0.01			0.95	7.1	0.06	0.5	55.7
4	CRUISE	0.42	30	72.00	0.27	2.0	0.84	6.6	15.8
5	DESCENT	0.05			0.45	3.3	0.17	1.3	26.4
6	HOVER - Dispatch ground rover	**0.25**			0.91	6.7	1.69	13.3	53.3
7	CLIMB	0.01			0.95	7.1	0.06	0.5	55.7
8	CRUISE	0.42	30	72.00	0.21	1.6	0.65	5.1	12.3
9	DESCENT	0.05			0.45	3.3	0.17	1.3	26.4
10	HOVER/LAND	0.08			0.73	5.4	0.45	3.6	42.8
11	CLIMB	0.01			0.95	7.1	0.06	0.5	55.7
12	CRUISE	0.42	30	72.00	0.21	1.6	0.66	5.2	12.5
13	HOVER - Redock	**0.25**			0.91	6.7	1.69	13.3	53.3
3	CLIMB	0.01			0.95	7.1	0.06	0.5	55.7
4	CRUISE	0.42	30	72.00	0.27	2.0	0.84	6.6	15.8
5	DESCENT	0.05			0.45	3.3	0.17	1.3	26.4
6	HOVER/LAND	0.02			0.91	6.7	0.13	1.1	53.3
							9.01	71.2	

*** Dispatch and Docking time available 30 minutes**

NOTE:This does not take into consideration the fact that the craft is getting lighter due to fuel consumption.

Table C3-5: Redocking Estimate Without Refueling

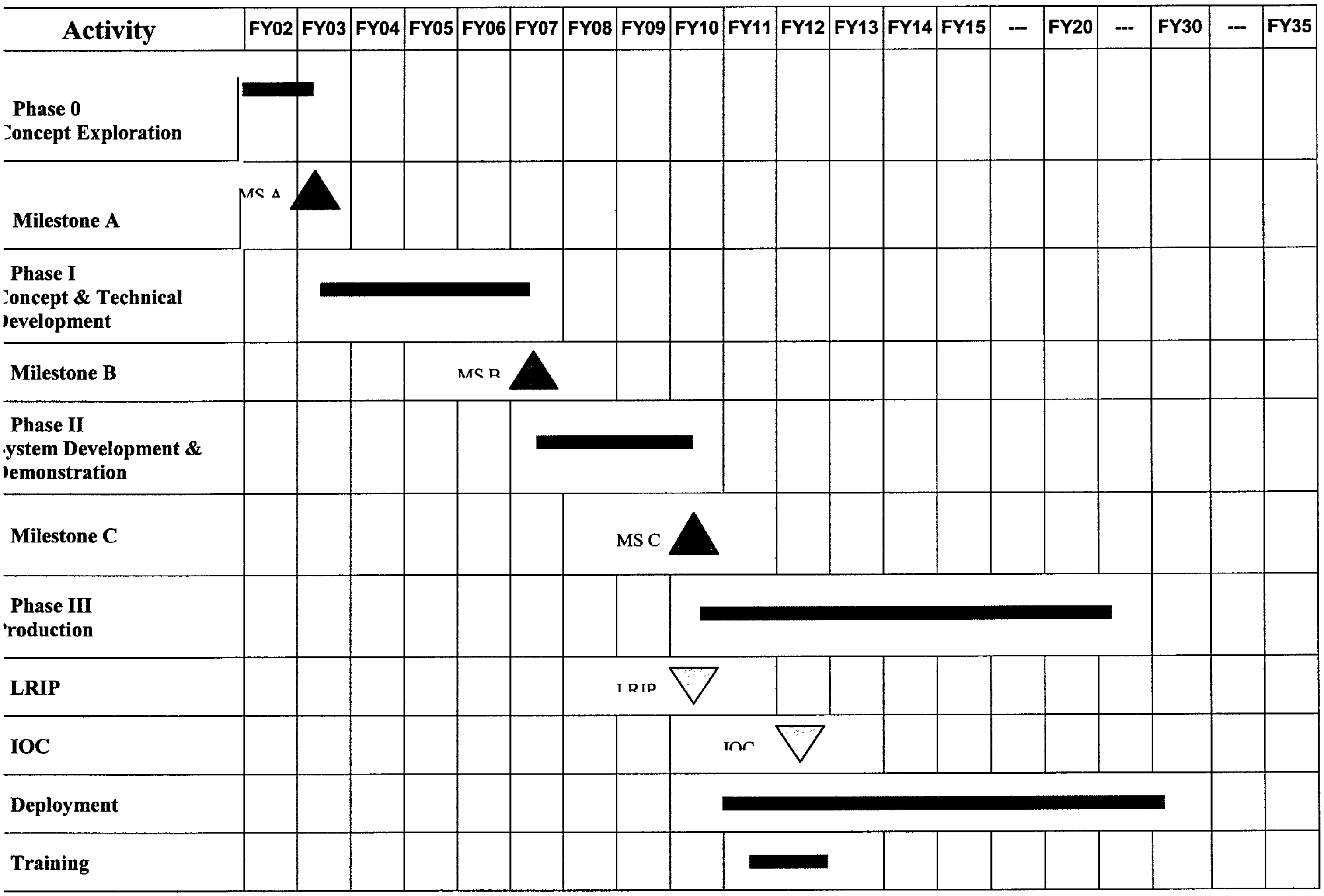
C4 - Programmatics

LINE #	WBS LEVEL	WORK BREAKDOWN STRUCTURE ELEMENTS
1.0	1	Unmanned Hybrid Vehicle
1.1	2	Air / Ground Vehicle
1.1.1	3	Frame
1.1.2	3	Propulsion / Power
1.1.3	3	Auxiliary Power
1.1.4	3	Vehicle Application Software
1.1.5	3	Vehicle System Software
1.1.6	3	Automatic Flight / Steering Control
1.1.7	3	Suspension / Steering
1.1.8	3	Communication / Identification
1.1.9	3	Navigation / Guidance
1.1.10	3	Central Computer
1.1.11	3	Data Display and Controls
1.1.12	3	Survivability
1.1.13	3	Reconnaissance
1.1.14	3	Central Integrated Checkout
1.1.15	3	Auxiliary Equipment
1.2	2	Systems Engineering / Program Management
1.2.1	3	Systems Engineering

1.2.2	3	Program Management
1.3	2	System Test and Evaluation
1.3.1	3	Development Test and Evaluation
1.3.2	3	Operational Test and Evaluation
1.3.3	3	Mock-ups
1.3.4	3	Test and Evaluation Support
1.3.5	3	Test Facilities
1.4	2	Training
1.4.1	3	Equipment
1.4.2	3	Services
1.4.3	3	Facilities

LINE #	**WBS LEVEL**	**WORK BREAKDOWN STRUCTURE ELEMENTS**
1.5	2	Data
1.5.1	3	Technical Publications
1.5.2	3	Engineering Data
1.5.3	3	Management Data
1.5.4	3	Support Data
1.5.5	3	Data Depository
1.6	2	Peculiar Support Equipment

1.6.1	3	Test and Measurement Equipment
1.6.2	3	Support and Handling Equipment
1.7	2	Common Support Equipment
1.7.1	3	Test and Measurement Equipment
1.7.2	3	Support and Handling Equipment
1.8	2	Operational / Site Activation
1.8.1	3	System Assembly, Installation, and Checkout on Site
1.8.2	3	Contractor Technical Support
1.8.3	3	Site Construction
1.8.4	3	Site / Vehicle Conversion
1.9	2	Industrial Facilities
1.9.1	3	Construction / Conversion / Expansion
1.9.2	3	Equipment Acquisition or Modernization
1.9.3	3	Maintenance (Industrial Facilities)
1.10	2	Initial Spares or Repair Parts
1.11	2	Sustainment
1.12	2	Disposal



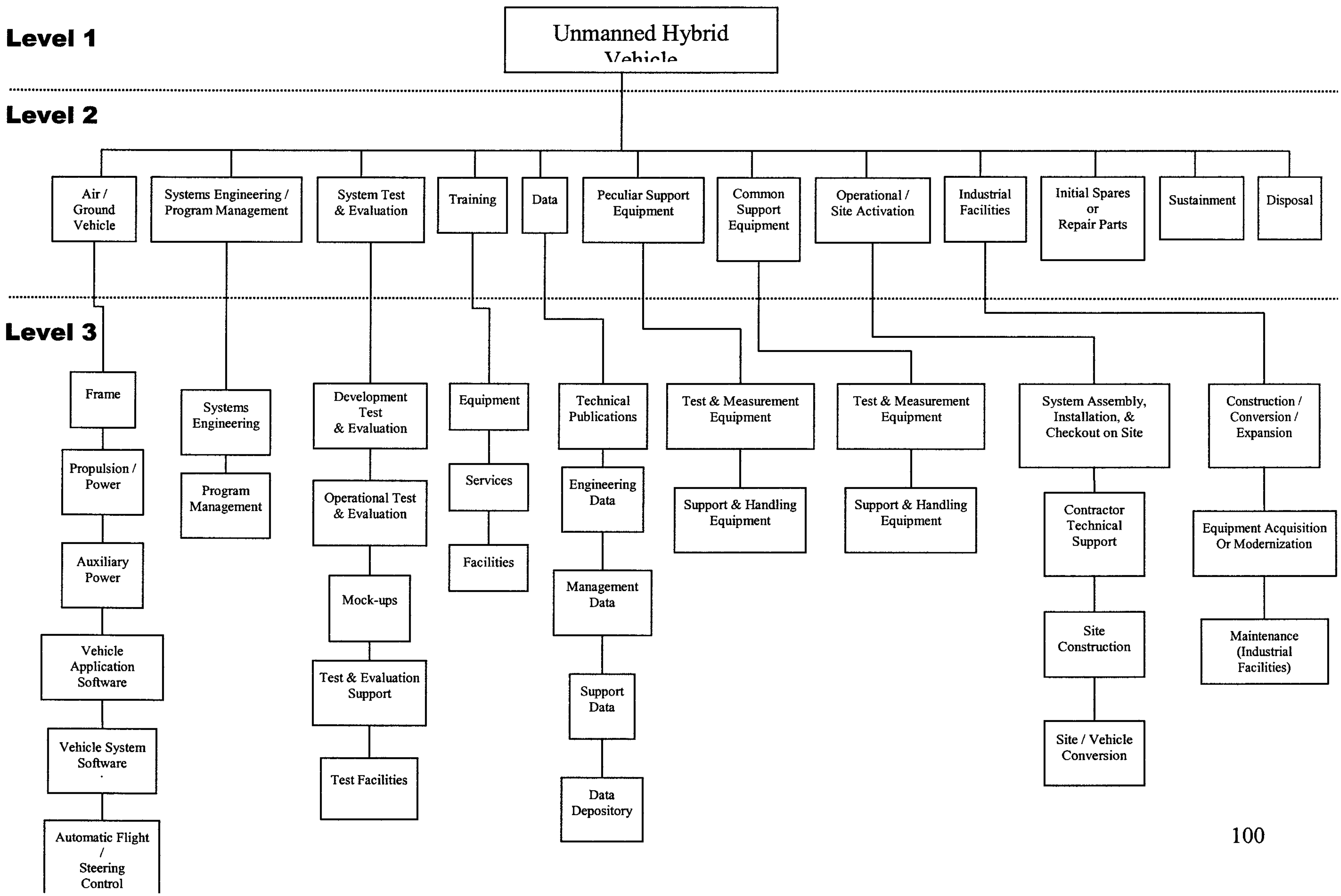
Activity
FY02
FY03
FY04
FY05
FY06
FY07
FY08
FY09
FY10
FY11
FY12
FY13
FY14
FY15

FY20

FY30

FY35
Phase 0
Concept Exploration
Milestone A
MS A
Phase I
Concept & Technical
Development
Milestone B
MS B
Phase II
System Development &
Demonstration
Milestone C
MS C
Phase III
Production
LRIP
LRIP
IOC
IOC
Deployment
Training

Disposal



Level 1
Unmanned Hybrid Vehicle
Level 2
Air / Ground Vehicle
Systems Engineering / Program Management
System Test & Evaluation
Training
Data
Peculiar Support Equipment
Common Support Equipment
Operational / Site Activation
Industrial Facilities
Initial Spares or Repair Parts
Sustainment
Disposal
Level 3
Frame
Propulsion / Power
Auxiliary Power
Vehicle Application Software
Vehicle System Software
Automatic Flight / Steering Control
Systems Engineering
Program Management
Development Test & Evaluation
Operational Test & Evaluation
Mock-ups
Test & Evaluation Support
Test Facilities
Equipment
Services
Facilities
Technical Publications
Engineering Data
Management Data
Support Data
Data Depository
Test & Measurement Equipment
Support & Handling Equipment
Test & Measurement Equipment
Support & Handling Equipment
System Assembly, Installation, & Checkout on Site
Contractor Technical Support
Site Construction
Site / Vehicle Conversion
Construction / Conversion / Expansion
Equipment Acquisition Or Modernization
Maintenance (Industrial Facilities)

Appendix D – Web Pages

Copies of web pages referenced in this volume are located on the "Unmanned Hybrid Vehicle" CD that was provided as a supplement to the deliverables.